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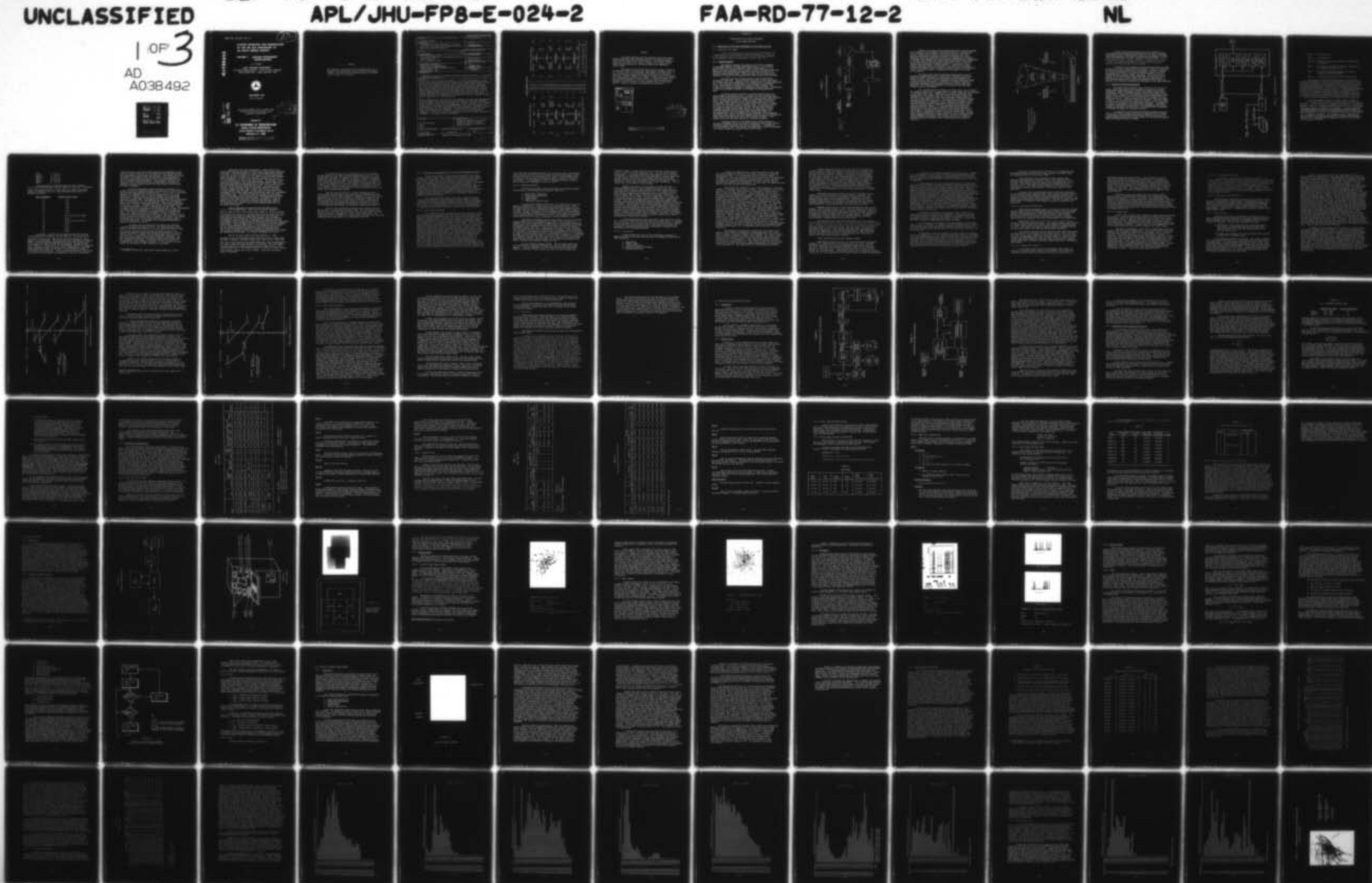

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AD A038492

Report No. FAA-RD-77-12, II

(12)

SYSTEM DEFINITION AND INVESTIGATION OF THE ON SITE PROCESSING OF EN ROUTE SENSOR SIGNALS

VOLUME 2 BEACON PROCESSING INVESTIGATION

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FINAL REPORT

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An Addendum to this work, concerned with beacon ringaround problems, is scheduled for publication August 1977.

16. Abstract

The objective of this program was twofold: (1) to define requirements from the primary radar system and from the Air Traffic Control Radar Beacon System (ATCRBS) for the en route automation portion of the National Airspace System (NAS) and (2) to unload the data line from the on-site surveillance system. The primary thrust of this investigation was directed towards the Common Digitizer (CD); the requirements placed on the CD by the Air Route Traffic Control Center's (ARTCC) Central Computer Complex, the processing capabilities and limitations of the CD and the requirements the CD places on the surveillance sensors. This report documents the analytical and empirical investigations that were conducted in these areas in support of the stated objectives.

Due to the magnitude of the results of this program, this report has been prepared in three volumes. This Volume II discusses processing of the ATCRBS (secondary radar) information within the Common Digitizer. Volume I consists of (1) a summary of major results, conclusions, and recommendations for the entire program, (2) a description of the work accomplished and results obtained in the area of primary radar processing, and (3) a discussion of the ATCRBS jitter problem from the overall surveillance system standpoint. Volumes I and II are essentially independent. Volume III contains the appendices which present backup information in support of the Volume I and II discussions.

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METRIC CONVERSION FACTORS

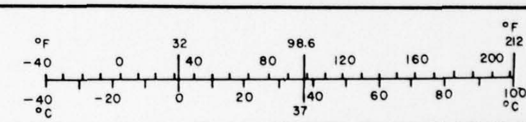
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report describes the work performed by The Johns Hopkins University Applied Physics Laboratory (APL) for the Federal Aviation Administration under contract DOT-FA75WA-3553. The Technical Representative for this effort is Dr. James A. Shannon of Air Traffic Control System Division (ARD-111) of the Systems Research and Development Service (SRDS).

This report is divided into three separate volumes. Volume II discusses processing of the secondary radar (beacon) information with the CD. Volumes II and I are essentially independent so that the reader mainly concerned with beacon processing can concentrate on Volume II and vice versa. Volume I consists of a summary of major results, conclusions, and recommendations from the entire report. In addition, Volume I also describes work completed in the area of primary radar processing (one exception to this is Section 4.2 which discusses jitter in the beacon system). Volume III contains the appendices for this report.

SECTION 8.0

INVESTIGATION OF THE BEACON PERFORMANCE
OF THE COMMON DIGITIZER

8.0 INVESTIGATION OF THE BEACON PERFORMANCE OF THE COMMON DIGITIZER

8.1 INTRODUCTION AND SUMMARY

Volume II contains Section 8 of the report, which describes the investigation into the beacon data processing performance of the CD. It is the companion volume to Volume I, which, for the most part, addresses the investigation into the CD processing of primary radar data.

8.1.1 Analysis Approach

This section discusses the analysis of the beacon performance of the Common Digitizer performed under Modification 1 to the contract. The objective listed in the Statement of Work of Modification 1 is "to analyze the beacon performance of the Common Digitizer (CD) paying particular attention to the automation requirements of the en route portion of the National Airspace System (NAS)". This broad objective was refined by the Laboratory to include the following specific steps in the analysis approach.

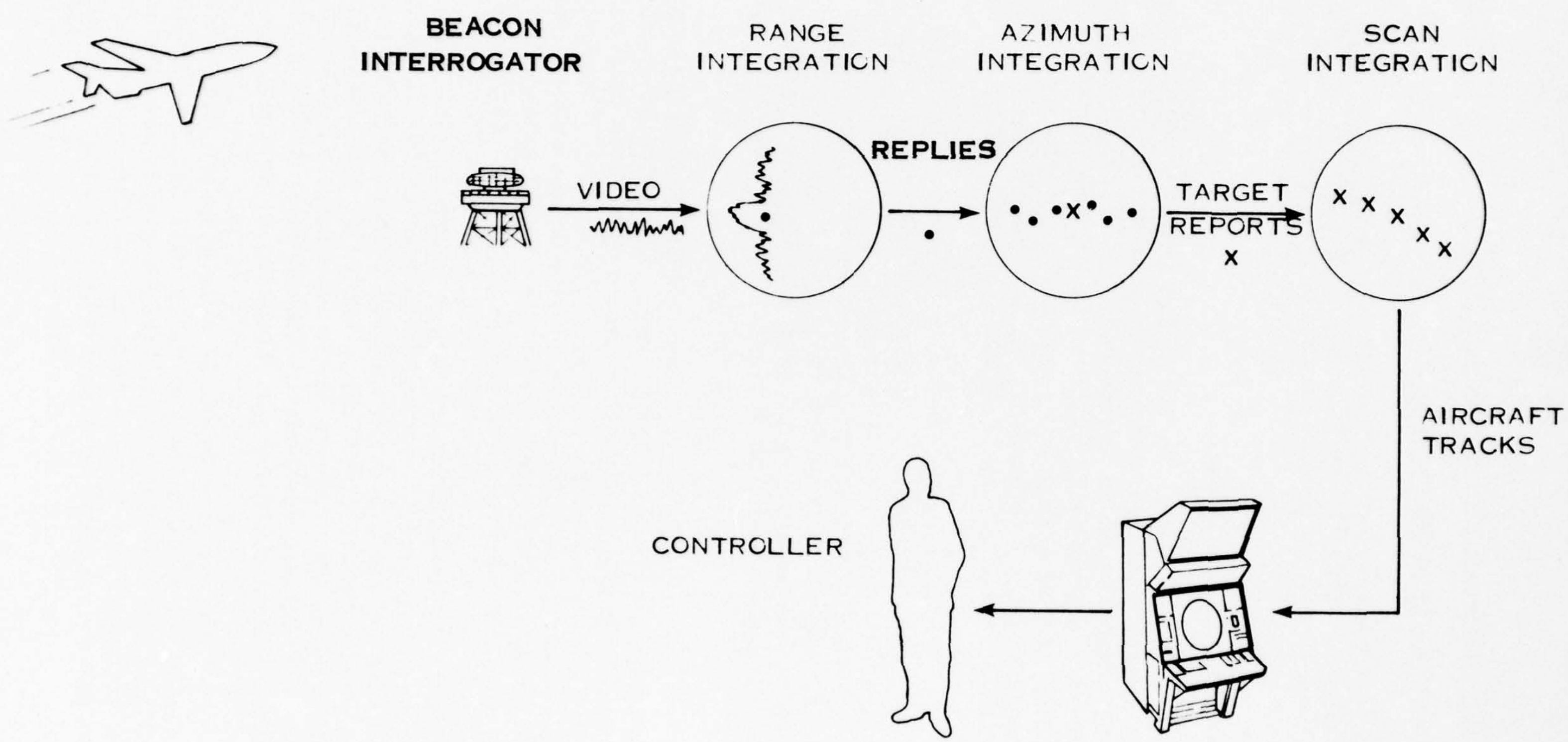
The first step was to isolate specific areas in which beacon processing is deficient. Special attention was given to those areas which were already known to be troublesome (e.g., azimuth jitter of target ambiguities, etc.). Once the primary problem areas were determined, the performance of the CD was studied to determine the causes for these problems. The results of the analyses performed are discussed and where possible, modifications to the CD are proposed to improve its performance in processing beacon data.

The beacon analysis was based on empirical observations of the CD processing of actual beacon data. In order to do this, recordings were made at three points along the processing chain from raw beacon video entering the CD to beacon reports exiting. Figure 8-1 illustrates this processing chain. The relevant functions of the CD are shown. Beacon video from the secondary radar receiver is first range integrated by the CD in order to detect the occurrence of beacon replies or hits. The ranges of replies that occur are noted and replies at the same range are then integrated in azimuth to produce beacon target reports. The three points at which recordings were made for this study include the incoming beacon video, the beacon replies, and the outgoing target reports (see Figure 8.1). The approach was to start the analysis at the conclusion of the processing chain (with target reports) and work backwards along the chain by investigating beacon replies and then beacon video, while reducing the amount of data analyzed and at the same time focusing in on specific problems.

The unique feature of this approach over previous analyses of the Beacon Performance of the CD is that in addition to beacon target reports, the beacon replies and beacon video are also considered. Consideration of CD processing at these levels allows the problem area in the CD's processing to be better isolated to a specific area in the CD logic.

FIGURE 8.1

BEACON PROCESSING



Analysis at the reply level and video levels have been made possible by the addition of new equipment to the NAFEC facilities. In particular, the CD at Elwood used to generate all the report and reply data, has a recently installed device called an Auxiliary Interpreter (AI), which, among other functions, allows beacon replies to be extracted and recorded in digital form on magnetic tape. Also recently completed was the installation of the Video Quantizer Recorder (VQR) machine which converts both primary and secondary analog video to digitized video which in turn can then be analyzed using processing by digital computers. In particular, using a computer generated display, the intensity of the video can be displayed in range and azimuth on static display for extended study of video characteristics. With analog signals, a meaningful static display of the video is not possible.

The target report analysis identified problem areas in the CD processing through examination of target reports, developed and applied methods to quantify and assess the significance of these problems, and finally selected a group of specific problems considered significant enough to warrant further investigation. Furthermore, the methods developed to assess the significance of the problems can also be used to assess the improvement in CD processing resulting from CD modifications that might be made to correct the problems.

Next, the replies used to generate the target report were considered. For example, problems such as jagged tracks or missing reports may be identified at the target report level. Examination of the target replies may show, hypothetically, that jagged tracks are caused by bad range timing in the placement of the replies in a range cell, resulting in range errors and also centroiding (azimuth) errors. This would tend to indicate processing problems in the beacon reply group or the target detection group. If the replies themselves are anomalous, it may be necessary to proceed further and study the beacon video to determine the video characteristics that cause the anomalous replies. If it was determined that certain video characteristics were resulting in anomalous replies being generated, a modification to the video quantizer section of the beacon reply group in the CD might be recommended to handle the problem causing video. At the report level, a large amount of data is analyzed, as the analysis proceeds further backwards along the processing chain, less data is analyzed, and fewer problems are considered. This reduction in data as the analysis proceeds through the processing chain is illustrated by the funnel in Figure 8.2.

COMMON DIGITIZER
BEACON ANALYSIS
APPROACH

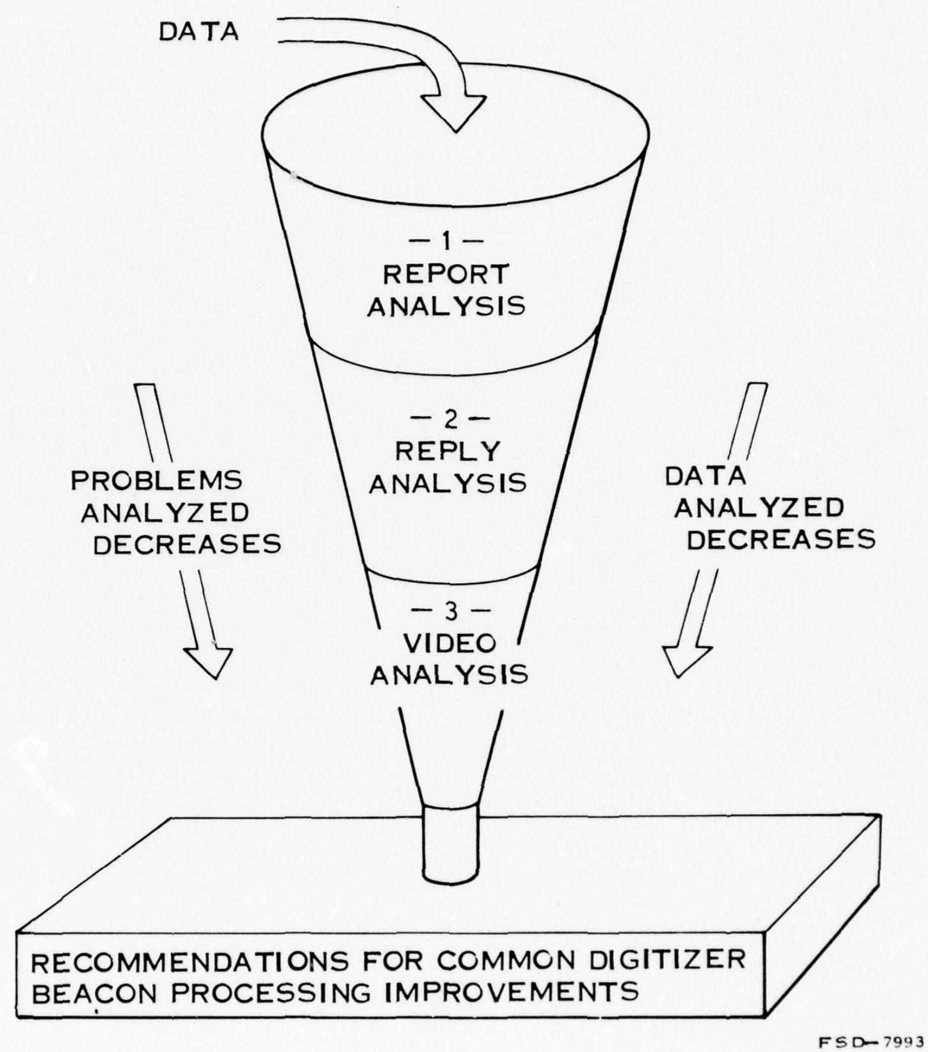


FIGURE 8.2

As noted on the figure, the objective of this analysis is to focus upon specific problems using beacon replies and video if necessary to determine as much as possible about causes for the problem and thereby enable recommendations to be made to improve beacon processing. Problems in obtaining government furnished tapes prior to suspension of the investigations curtailed, in places, attempts to identify specific trends and make corresponding recommendations. However, many interesting anomalies were identified and will be discussed.

In Section 8.2 the equipment and data collection process at NAFEC, as well as the data collected itself are discussed. Section 8.3 addresses the APL data reduction facilities and processing. Sections 8.4 through 8.6 present the results of the analysis performed at each of the three processing levels (reports, replies, and video). While the section on analysis of reports contains useful information, the sections of prime interest are 8.5 and 8.6 which address the reply and video analyses. These sections present data in forms only available recently due to the addition of the Auxiliary Interpreter and VQR machine to the NAFEC facilities.

8.1.2 Overview of System Being Analyzed

The system under discussion in this section is part of the Air Traffic Control Radar Beacon System (ATCRBS) and consists of airborne transponders, ground interrogator receiver (Air Traffic Control Beacon Interrogator, ATCBI), processing equipment (CD and ARTCC complex) and an antenna system. Figure 8.3 illustrates the airborne transponder and that portion of the system located at the antenna site at Elwood, namely the ATCBI-3 and the CD. There are several versions of the ATCBI, up through an ATCBI-4. The one installed at Elwood is an ATCBI-3. The Search Radar is shown since its video is also processed by the CD, and the range timing in the CD is synchronized to the search radar pretrigger. The ATCBI-3 is likewise synchronized to the search radar pretrigger providing proper ranging for both search and beacon data. The figure should be referenced as necessary throughout the following discussion.

In operation, an interrogation pulse-group transmitted from the ATCBI via the antenna triggers each airborne transponder that is capable of responding to the mode interrogated and located in the direction the antenna mainbeam within 256 nmi of the antenna. The following interrogation modes are presently defined for ATCRBS.

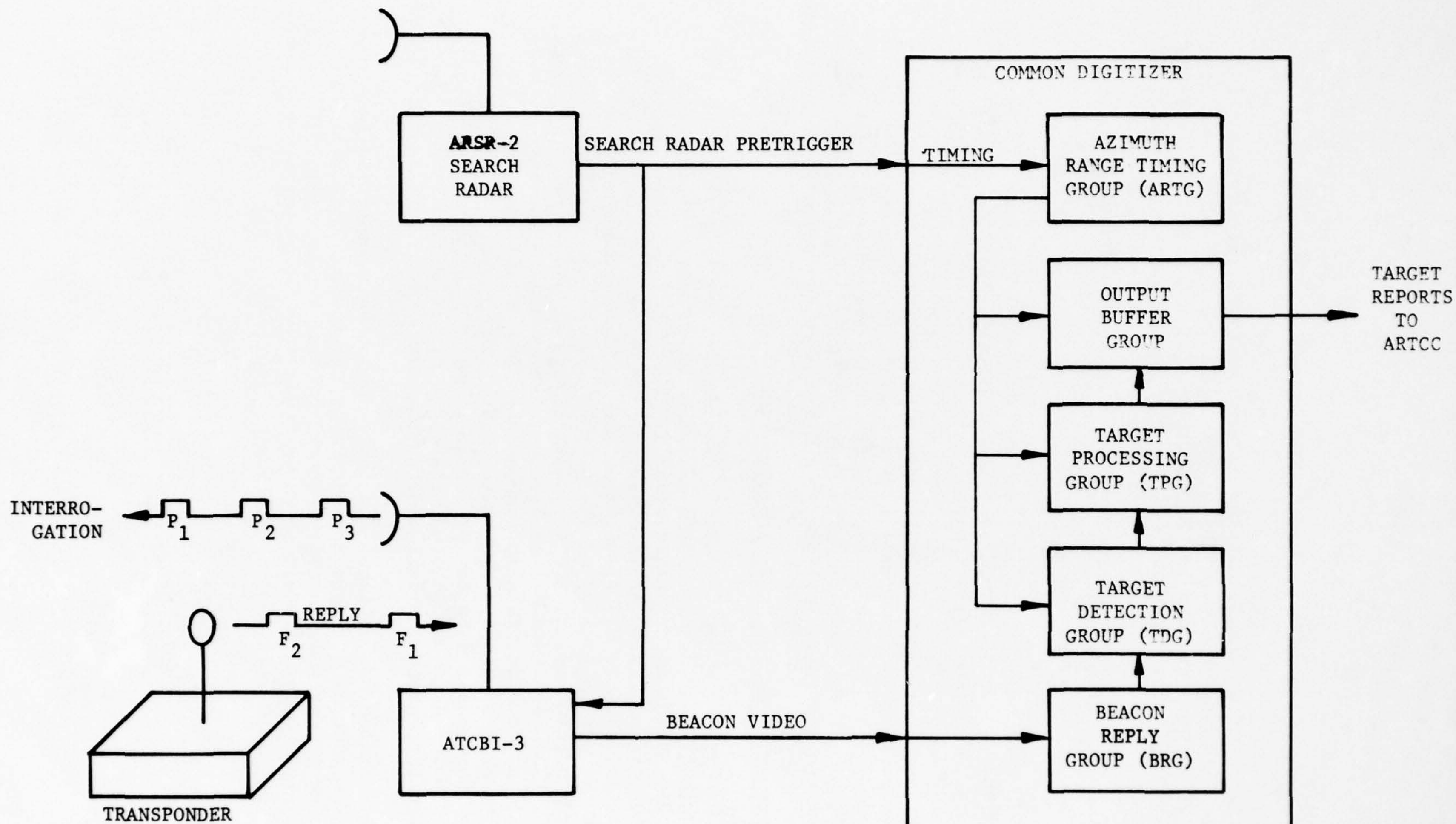


FIGURE 8.3 BEACON DATA PROCESSING

Mode 1 - for military use

Mode 2 - for military use

Mode 3/A - to initiate transponder response for identification and tracking

Mode B - to initiate transponder response for identification and tracking (not used in U. S.)

Mode C - to initiate transponder response for automatic pressure altitude transmissions

Mode D - for future expansion (not used at present time)

The interrogation modes of primary interest to this analysis are Mode 3/A and Mode C. All civilian transponders can respond to Mode 3/A interrogations though some cannot respond to Mode C interrogations. When the airborne transponder is triggered by the interrogation, it transmits a multiple pulse reply group. The range of the airborne transponder is determined from the round trip transit time (i.e, interrogations transmitted to reply received time) and azimuth information is determined from the direction of the mainbeam. The multiple pulse reply group, in the case of a reply to a Mode 3/A interrogation, contains the encoded beacon code for identification and is used for detection and tracking. In the case of a reply to a Mode C interrogation, the pressure altitude is encoded.

Each interrogation consists of a pulse triplet of pulses P_1, P_2, and P_3. Pulses P_1 and P_3 are transmitted directionally in the antenna mainbeam. Pulse P_2 is transmitted omnidirectionally for use in suppressing transponder responses to sidelobe interrogations. Sidelobe suppression is a feature that is included on all new transponders which measures the relative amplitude of P_1 and P_2 to determine the origin of an interrogation (i.e., mainbeam or sidelobe). The transponder will be suppressed and will not reply if the interrogation was from a sidelobe of the antenna. The mode of the interrogation is designated by the time interval between pulse P_1 and P_3 as follows:

Mode 1	3 ± 0.1 μs
Mode 2	5 ± 0.2 μs
Mode 3/A	8 ± 0.2 μs
Mode B	17 ± 0.2 μs
Mode C	21 ± 0.2 μs
Mode D	25 ± 0.2 μs

The most elementary transponder reply is a pair of pulses, (F_1, F_2) called framing pulses, that are spaced 20.3 μsec apart. Information pulses (for encoding altitude or beacon code) occur between the framing pulses at intervals of 1.45 μsec. Each information pulse position is designated as follows:

Pulse Designation	Position from F_1 (μsec)
C_1	1.45
A_1	2.90
C_2	4.35
A_2	5.80
C_4	7.25
A_4	8.70
X	10.15 (Not used in ATCRBS)
B_1	11.60
D_1	13.05 (Not used in Mode C)
B_2	14.50
D_2	15.95
B_4	17.40
D_4	18.85

In addition, a Special Position Identification (SPI) Pulse may be transmitted with the reply at 4.35 μsec after F_2. This pulse will be transmitted with each reply only when the pilot has activated the "ident" feature of the transponder. The X pulse position is not used in the present ATCRBS. The twelve remaining information bits allow 4096 different codes to be selected for reply to a Mode 3/A interrogation. Encoded altitude from - 1000 feet to 127000 feet in 100 foot increments can also be transmitted via the information pulses in reply to a Mode C interrogation. The transponder replies are received by the ATCBI receiver which incorporates a sensitivity time control STC. This varies the sensitivity of the receiver as a function of time elapsed from transmission of the last interrogation,

so that the gain is low when receiving replies from transponders at close range but increases with time so that higher gains are used when replies from transponders at longer ranges are received. This feature will reduce the number of detectable replies received though antenna sidelobes for those cases where sidelobe suppression fails or the transponder does not have the sidelobe suppression feature. From the ATCBI receiver, the replies are sent to the CD where they are digitized* and processed to determine the range, azimuth, beacon code, and altitude of each aircraft carrying a transponder.

The beacon interrogator antenna at Elwood is rotating at 9.6 seconds per scan and transmitting beacon interrogations at a rate of 360 per second (beacon pulse repetition frequency, PRF). If the system is functioning properly, the transponder will only be interrogated while it is in the mainbeam of the antenna, which is roughly 3 degrees for the hog trough type antenna. Taking into account the antenna scan rate, beacon pulse repetition frequency (PRF), and beamwidth, the transponder will be interrogated about 29 times while it is in the mainbeam each scan. The interrogation modes can be interlaced in selectable patterns. Assume that an interlace of 3/A, 3/A, C is used. This means that two Mode 3/A interrogations will be transmitted followed by a Mode C interrogation over and over. This is roughly 19 Mode 3/A interrogation and replies and about 10 Mode C interrogation and replies while the transponder is in the mainbeam of the antenna per scan. The 19 Mode 3/A replies are processed by the CD to determine the beacon code, range, and azimuth of the target. The Mode C replies are processed to determine the altitude of the target. Note that Mode C replies are not processed to determine range and azimuth of the target. The received replies are sent to the CD which first turns them into digital signals for further processing. The remainder of this discussion addresses the digital processing of the replies.

The beacon video is quantized by the beacon video quantizer in the Beacon Reply Group (BRG) of the CD. The quantized video is then sampled to determine the occurrence of an F_1-F_2 bracket pair and, if found, the quantized information pulses between the bracket pulses and SPI position are sampled to extract the information (either code or altitude) from the reply. It is possible that two transponders located close to each other in the airspace could produce replies that overlapped. The BRG can sometimes detect this and determine whether the pulse positions are overlapped or interleaved. If the pulse positions are found to be overlapped, the reply is flagged as garbled. If the positions are interleaved, the beacon data for both replies can be processed.

* The ATCBI-4 receiver will send replies already digitized to the CD.

Immediately after each interrogation, a range counter in the Azimuth Range Timing Group (ARTG) of the CD starts counting from essentially zero range. The space between zero range to the maximum range processed by the CD, 256 nmi, is divided into one thousand 1/4 nmi divisions called range cells which are counted out by the range counter after the interrogation is transmitted. As replies are received, the range cell they fall in is determined by the count on the range counter. The process of transmitting an interrogation, then counting through the thousand range cells while receiving replies and assigning them to range cells is called a sweep. With the 360 PRF there are 360 sweeps per second. An eleven bit shift register, called a sliding window, is associated with each range cell. It will be assumed that data, ones or zeros, are shifted in the eleven bit shift register from the right. On each sweep, for which Mode 3/A was interrogated, the sliding window associated with each range cell is processed by shifting it left. If a Mode 3/A reply was received for a particular range on that sweep, a hit is shifted into the sliding window by shifting a one into the sliding window from the right. If no Mode 3/A reply was received for that range cell after a Mode 3/A interrogation, a miss is shifted in as a zero. An adder in the target detection group (TDG) of the CD determines the number of hits in every sliding window each time the window is processed.

Several thresholds are associated with the number of hits counted in the sliding window. First is the validation threshold T_V. When the number of hits in the sliding window reaches T_V, validation begins. The TDG group will request an in-process address from the Target Processing Group (TPG) in the CD and the target report is said to be in process. The information word contained in the next ungarbled reply for each mode interrogated is stored by the TPG. Thereafter, the information word for each ungarbled reply is compared with the stored word for each mode interrogated respectively. If the information agrees, the stored word has been validated and no further comparison takes place. If the information does not agree, the new information replaces the currently stored word for that mode. Thus, after the validation threshold is reached, two ungarbled replies with the same information for each mode interrogated are required to validate the information for that mode. T_V at Elwood is normally set to five.

Next is the target report lead edge threshold, T_L. When the number of hits in the sliding window reaches this value, a target report lead edge is declared. Normally at Elwood, T_L is set for six, so that six hits in any eleven (eleven is the sliding window size) Mode 3/A interrogation will cause a target lead edge threshold to be declared. When this happens, the target report will remain in-process until the number of hits in the sliding window drops to a preselected threshold T_T called the target trailing edge threshold, normally set to two at Elwood. After this, the target report is completed.

An azimuth counter is also functioning in the CD to determine antenna position as the number of azimuth change pulses or ACP's. There are 4096 ACP's per scan. The azimuth at which T_L is reached, called the azimuth start (AZ START), is added to the azimuth at which T_T is reached, called the azimuth stop (AZ STOP), both expressed in ACP's. A division by two is done by putting the sum in a shift register and shifting right. As a result, the remainder of 1/2 ACP, if it exists, is truncated. The result of the division, the uncorrected center azimuth, is then corrected by a preset azimuth correction factor, which is -3 ACP's at Elwood, and the final value is the corrected target azimuth.

Thus the target is detected by azimuth integrations using a sliding window, and the range of the target report is determined by which range cells the Mode 3/A target replies are assigned to by the range counter. Target detection is effected by reaching a leading edge threshold of six Mode 3/A replies or hits out of eleven Mode 3/A replies. Target azimuth is determined after the trailing edge threshold of two Mode 3/A hits out of eleven Mode 3/A interrogations is reached and computing the azimuth that is roughly half way between the leading and trailing edge thresholds.

The CD is also concurrently processing radar video in much the same way that it is processing the beacon video. If an in-process beacon report occurs in the same range cell as an in-process radar report, a single in-process address is assigned and a single report is generated. The target report will be designated as a beacon report which was radar reinforced. A separate search radar report is not generated in this case.

8.1.3 Conclusions and Recommendations for the Beacon Performance Analysis

The proposed approach to this analysis consisted of three steps - analysis of beacon target reports, analysis of beacon replies, and analysis of quantized beacon video. The analysis was to proceed by selecting beacon target report anomalies during the analysis of the beacon reports, then study the associated beacon replies and beacon video as necessary to determine the causes and ultimately solutions to the identified anomalies. The conclusions and recommendations section suggested by the analysis approach should then start with the selected anomalies indicated and then follow through with the associated results obtained at each level for the anomalies. A separate section would then be provided for additional information of interest discovered during the analysis but not necessarily related to the originally identified anomalies.

This section generally follows this format. However, the data collection was impaired at various stages during the analysis, preventing a complete data set with associated anomalous reports, replies, and quantized beacon video. The results obtained, however, are not discouraging though the conclusions and recommendations do not list exactly the information that the analysis approach would be expected to provide in the ideal situation.

8.1.3.1 Data Collection Problem

The primary data collection problems were the collection of beacon reply data and quantized beacon video data. Collection of the beacon reply data was hampered by problems with the actual data collection device, the auxiliary interpreter (AI). This device is connected to the Common Digitizer (CD) and accumulates in real time the beacon replies as detected by the CD. The information is then written on magnetic computer tapes, called AI Mode 2 Beacon Reply Tapes (also just Mode 2 tapes or Reply Tapes). The first problem during collection of this data was the selection of the correct wirestrap options to record beacon target run length and beacon target reports. This problem was solved after it was discovered that some data had been collected with these wirestrap options selected. The second problem involved RF interference from the search radar and/or beacon interrogator transmitters that directly affects the recording of the Mode 2 tapes. This problem causes recording errors such as parity errors or checksum errors to appear on the Mode 2 tapes. It was determined that good clean recordings of AI Mode 2 data could only be made by playing previously recorded tapes of beacon and radar video through the CD with the transmitting equipment turned off. As a result, no reply data can be recorded when the transmitters are on and data directly from the receiver is used as input to the CD. Evidence that there are possibly significant differences between report data emanating from

the CD when real time radar and beacon video are used as inputs and resulting report data when an FR-950 analog recording of the same video signal is used has been found and is also discussed in this report. These differences may be present at the reply level and therefore could be recorded on the Mode 2 reply tapes. It is recommended that the AI recording problems be solved so that its use is not restricted to analog recordings.

8.1.3.2 Anomalies Identified

Five different problems that have potential for improvement through modifications to CD processing were identified. These are:

1. Target Report Ambiguities
2. Radar-Beacon Misalignments
3. Missing Reports
4. Jagged Tracks
5. Inconsistent Reported Codes

A target report ambiguity occurs when, on a single scan, two or more reports corresponding to a single aircraft are outputted by the CD. These additional reports result in unnecessary information being transmitted across the modem lines and create an additional burden on the 9020 computer system at the ARTCC. Further, the display of these ambiguous reports to the controller creates an additional problem for him, thus reducing his capacity for carrying out his primary purpose of directing air traffic. The existence of ambiguous target reports will also result in problems to future automation of NAS.

Radar-beacon misalignment refers to the failure of the CD to correlate a beacon report with its corresponding radar report. When functioning as designed, the CD will recognize that incoming radar hits correspond to incoming beacon replies from the same target and will produce a single beacon report that is flagged as radar reinforced. When the CD fails to do this, two reports, a radar and a beacon report, will be transmitted to the ARTCC. While it appears that controllers are not overly concerned about the display of this extra report, its existence on the display must still be given consideration by the controller, at least to the extent that he observes it and decides to ignore it. As controller workloads are often extremely heavy, it would be best to eliminate the display of all unnecessary reports. The extra radar reports place an extra burden on the modem lines and the 9020 computer systems. It was therefore considered worthwhile to consider this problem for additional study.

The next problem is missing reports. When the target report data for several scans is displayed simultaneously, aircraft flight paths become apparent. By visual inspection, it can be seen that aircraft tracks exist. Ideally, on each scan, a beacon report will occur for each existing track.

Sometimes, however, a report will not occur on the track, though one does occur on a previous scan and subsequent scans. Such an event is called a missing report. The target report data being displayed to the controller is tracked by the 9020 system before being displayed. A missing report into the 9020 system, occurring on a track already established by the 9020 tracker, will result in a report being displayed to the controller which is developed by use of predicted position based on past information. This, of course, has a direct affect on track accuracy.

Jagged tracks refer to the occurrence of tracks for which a smooth flight path cannot be drawn through the reports on the track. It is assumed that the aircraft which generated the target reports forming a track prescribed a smooth flight path in the air. If a smooth line were drawn through a jagged track to approximate the aircraft flight path, it would be evident that the target reports were deviating from the line. As en route aircraft are not likely to follow a jagged path, it is assumed that a centroiding problem or ranging problem has resulted when a jagged track is found. Such tracks were frequently observed using the display program. Improper centroiding and ranging can present significant problems to the system at the ARTCC. For one thing, trackers normally assume a smooth flight path, and look for a target report to occur at a position predicted on the basis of a smooth prediction using past track parameters. When a target report does not occur at its predicted position, the tracker must either coast (produce a predicted report), or go through some additional logic to find the misplaced report. In either case, tracker load is increased. Furthermore, the accuracy with which the target position is known is reduced because of the incorrect determination of target report position.

An incorrectly reported code occurs when a target report on a track has a code that is different from those reports occurring prior to or subsequent to it on the same track. As beacon code is used by the controller to identify aircraft which he is controlling and also by the tracker in the 9020, the occurrence of incorrectly reported codes is potentially a problem and will become more so with increased automation.

8.1.3.2.1 Ambiguities

It was observed that there are five identifiable categories of ambiguities based on separation existing between the ambiguous target reports. These classes are:

1. Range Splits
2. Azimuth Splits
3. Sidelobe Ambiguities
4. Reflection Outside the Mainbeam
5. Mainbeam Reflections

Although the ambiguities are classified according to their range and azimuth separations, this factor is closely related to the mechanism that generated them. It is the mechanism that is of primary concern. In consideration of this, the discussion of the characteristics of the ambiguities is closely tied to the mechanisms for generating them. In some instances the ambiguities separation characteristics were first observed, then the mechanism for generation was hypothesized. In other cases, the ambiguities were known to exist and the cause was already known.

Range splits were observed to occur in pairs separated by less than (usually) 3° in azimuth and 0.125 nmi in range. Less frequently, they occurred separated by 0.250 nmi. Range splitting is observed for targets that are part of easily distinguished tracks. Thus, coupled with the 3° azimuth separation which is approximately a beamwidth, indicates that the range split is generated entirely during the mainbeam. The distribution of azimuth separations for range splits, presented later in this section, shows that the azimuth separation most favored is 0°. Since two target reports cannot be in the same range cell at the same azimuth, this is evidence that the range split elements indeed are generated in adjacent range cells. The range cells are 1/4 nmi, but target report range in a range cell is reported to the nearest 1/8 nmi (upper or lower half of a range cell), thus targets separated by an 1/8 nmi can be in adjacent range cells. Although a single aircraft is generating the replies used to form the report, the replies may fall in different range cells if the target lies sufficiently close to a range cell boundary for inherent system range jitter to cause the replies to jump between range cells. This is assumed to be the basis for range split generation. The replies from a single target are randomly being placed by the CD in one of two adjacent range cells in sufficient quantities to declare a target present in both range cells. The characteristics of range splits are that they generally occur in pairs, fall in adjacent range cells with an associated range separation usually of 1/8 nmi but sometimes 1/4 nmi, and are generated during a mainbeam interrogation with a corresponding azimuth separation of usually less than 3°.

The mechanism for generating an azimuth split was assumed to be a fading of beacon replies and subsequent strengthening again of the replies while the target is being interrogated in the mainbeam. The fading of replies must be sufficient to declare a target report complete, then, enough strong replies must be received to declare a new target report before the actual aircraft is out of the mainbeam. In this case all the replies are assumed to be placed in the same range cell. Thus, azimuth splits will have the same range and, since they occur during a mainbeam interrogation, be separated by no more than about 3°. They were observed to occur exclusively in pairs.

Sidelobe ambiguities result when target reports are generated by a single aircraft through interrogation by two or more of the antenna lobes. This will normally include the mainbeam interrogations and interrogations through one or more sidelobes. Normally, the reports will be generated at the same range. However, the time between generation of sidelobe elements is much greater than that of range or azimuth splits since the antenna has turned through more than the 3° of mainbeam beamwidth and, if a target has a radial velocity to or from the sensor, the range may change slightly between the generation of successive elements forming a sidelobe ambiguity. Thus sidelobes occur at azimuth separation larger than a beamwidth and at almost the same range. Sidelobes usually occur in pairs, but are more likely than the other ambiguities to occur in larger group sizes, as observed from the data.

Reflections are generated when an aircraft is interrogated by the mainbeam via a reflecting surface, and replies through a sidelobe. The report generated by the reflected interrogations along with the normally generated target report, form an ambiguity pair. Reflections will be at different ranges because of the different interrogation/reply path lengths, different azimuths because the mainbeam is not pointed at the target at all during generation of the reflected report, and occur mostly in pairs.

Mainbeam reflections have a large range separation but occur in the mainbeam. They are almost always in pairs. The term "mainbeam reflection" was given to these ambiguities before their cause had been determined. There is evidence to indicate that they are generated in much the way that range splits are generated, though the range cells are no longer adjacent. An analysis of range jitter in system shows that very large deviations are possible, though unlikely. Mainbeam reflections were quite rare.

The ambiguities were detected by searching for two or more targets per scan with the same discrete beacon code, then classified based on their separations. Mainbeam reflections and azimuth splits were so infrequently detected that they are considered a negligible problem. Many "reflections" were detected but these were found to be two actual aircraft that were simply squawking the same discrete beacon code. Thus sidelobe ambiguities and range splits were the only real ambiguities detected at significant levels. While reflections were not a problem in the data used for this analysis, other sites may, of course, have a more severe reflection problem.

Actual rates varied within some reasonable ranges.

Range Splits occurred at about a 1% to 3% rate usually and sometimes as high as 4%. Sidelobes were usually between about 0.5% and 1%. Mainbeam Reflection occurred at less than a 0.3% rate while Azimuth Splits were less than 0.1%. Reflections are considered negligible because 1) real reflection occurred at a low rate, and 2) reflections are best solved by proper antenna siting - not CD modifications. Sophisticated software can be developed to reduce reflections, but such techniques are not within the scope of simple CD modifications.

The majority of the observed ambiguities occurred in pairs. Azimuth Splits were always pairs and indeed it can be shown that theoretically they must be only pairs. Also, Range Splits, Mainbeam Reflections, and Sidelobes are also mostly pairs though sidelobes have more non-pairs than the other types of ambiguities.

It was observed in the case of Range Splits that for the majority of range splits with two Mode C reports in the group, both reports had the same altitude. However, in most cases, either no Mode C reports were present or one Mode C report was present and one non-Mode C report was present. This was similarly observed for sidelobes and mainbeam reflection but not reflections. This is evidence that at least one of the reports in the group was comprised of fewer replies than a normal report. Because a normal mode interlace pattern has more Mode 3/A replies than Mode C replies, there were sufficient Mode 3/A replies to declare both reports but not enough Mode C replies to determine altitude for both reports. In the case of Range Split and Mainbeam Reflections, this idea is consistent with the range jitter theory for generations of the ambiguities. That is, the successive replies are jittering back and forth between range cells with a sufficient amount in each cell to declare a target. For Range Splits, the cells are adjacent. For Mainbeam Reflections the cells are not adjacent. Naturally, the larger jitters are less probable and Mainbeam Reflections are therefore rare.

A single tape was made with an interlace of 3/A, C which has an equal number of Mode 3/A and Mode C interrogations. This was the only tape for which the majority of Range Splits, Sidelobes, and Mainbeam Reflections did not have one Mode C report and one non-Mode C report (i.e., usually both were Mode C reports for ambiguities detected on this tape).

It was found that the ambiguity rates were dependent upon the video input as well as CD factors. For example, differences between results obtained by playing the same FR-950 tape through at different times were obtained as well as differences between FR-950 results and real time results from which the FR-950 was made.

An experiment was done to determine the effect of Mode 3/A interrogation rate on ambiguities. For the interlace patterns with fewer 3/A interrogations the sidelobe and range split rates were lower than for interlace patterns with higher Mode 3/A interrogation rates. This is also consistent with the mechanisms used to describe the generation of these ambiguities. That is, in each case, the extra reports are being generated by fewer than normal replies. Thus (realizing that detection is based only on 3/A replies) when fewer 3/A interrogations occur some of these "extra reports" are not detected.

There was no evidence found to indicate that the ambiguities were particularly spatially distributed in range, azimuth, or altitude, except for sidelobes which tend to be close in range.

Since range splits were considered the major problem, some additional characterization was done for them. It was found that 95% of the range splits detected were less than 3° apart and separated by 1/8 nmi in range. The azimuth separation distribution was symmetric about 0° with a peak at 0°. This shows that the generation of the report pairs is occurring simultaneously, which supports a range jitter theory for their generation.

It appears that the NADIF modification at Elwood was responsible for the addition of some sidelobe problems. While the actual overall sidelobe rate was not significantly affected, some severe problems existed at close ranges that were not present before the NADIF modification was installed. The problem is approaching ring around proportions. This was, of course, observed only at NAFEC. No attempt to draw a blanket conclusion is implied by this observation.

8.1.3.2.2 Radar-Beacon Misalignments

Radar-beacon misalignment refers to the failure of the CD to properly correlate beacon returns and corresponding radar returns from the same target. Proper correlation results in a single beacon report being outputted by the CD with a flag indicating that it is radar reinforced. When the radar and beacon returns are not properly correlated, two reports, a radar and beacon report, are outputted. This has an adverse affect on the ATCRBS load.

Radar-beacon correlation failure is a result of range variations between the radar and beacon processing. This range variation usually consists of a small constant offset and a varying offset between the range processing of the CD. As a result, even when the constant offset is completely removed, the time varying offset will sometimes prevent proper correlation.

As a result, there are two major reasons why 100% radar reinforcement of beacon reports is not possible with the present system. First, the radar blip-scan is never unity; therefore in some cases there will be beacon reports for which a corresponding radar report was never declared. Second, the time varying range offset between the radar and beacon processing will sometimes prevent radar-beacon correlation even when a beacon report has a corresponding radar report.

8.1.3.2.3 Missing Beacon Reports

As the beacon reports from each transponder equipped target are received on successive scans, a beacon track is formed. If a report were outputted for every track on every scan, the ratio of the beacon hits to

scans (beacon blip-scan) would be unity. This of course, is not the case which signifies the existence of missing reports. The purpose for undertaking the study of missing reports was to see if some modifications to the CD processing could be made to improve the beacon blip-scan ratio. Insufficient data was analyzed to say much about a typical beacon blip-scan number. For a particular data set, the blip-scan obtained was .87 which is probably a typical value. This says that about 13% of the beacon reports are missing. Again, it should be emphasized that this is based on a very limited analysis.

Some beacon tracks were examined using the computer display system and cases of missing reports were found. The corresponding reply data was then displayed. For the cases studied, the missing reports were always due to insufficient replies to declare a target leading edge. Additional analysis is required before any important conclusion can be drawn; however, it is quite possible that the beacon lead edge threshold (T_L) could be lowered to permit detection of some of the otherwise missing reports without strongly affecting the beacon false target rate. New analysis would be required tc obtain an optimum setting for T_L.

8.1.3.2.4 Jagged Tracks

Since en route aircraft usually prescribe a smooth flight path through the airspace, it would be expected that a smooth line connecting the corresponding target reports to show its flight path could be drawn. This, however, is not always the case. Sometimes the target reports will appear to form a very jagged track. A limited analysis of the degree to which this jagged line occurs is described in Section 7. Results show that track jaggedness is caused by poor centroiding rather than incorrect ranging of the target reports.

The replies corresponding to some reports forming jagged tracks were examined using the computer display system. It was noted that the problem was primarily poor centroiding, rather than a range problem, and was a result of the effect that missing replies have on the centroiding of the report. In addition to replies actually being missing, range jitter problems at the reply level could cause some replies to be placed in a different range cell. Then, centroiding in own cell will be carried out as if these wayward replies were missing altogether. Thus, range jitter effects can indirectly cause poor centroiding. There are alternative methods of centroiding available. Further analysis could more accurately quantify the effects of missing replies on centroiding. It may reveal that one of the alternative techniques would function more reliably. This has not been verified thus far.

8.1.3.2.5 Inconsistent Reported Code

An analysis of code deviation is discussed in Section 7. The limited quantity of data analyzed showed that the majority of code deviations was caused by one of two events. First, on almost half of the occurrences the code deviated to 0000 which is what the CD outputs if the beacon code was too garbled to decode. The majority of the remaining deviations involved a difference in only one bit position (out of 12 possible) from the correct code. Insufficient analysis has been done to prepare a solution. There are, however, definite possibilities for improvement through modification of the code processing in the CD.

8.1.3.3 Target Report Characteristics

The most notable information extracted from this analysis involves the spatial distributions of target reports. Histogram data showing distributions of target reports in range, azimuth, and altitude were developed. There was no typical distribution in any of these dimensions. Quite often in an analysis, one will assume a "typical" spatial distribution for the target reports. Therefore, it is significant to note that a typical distribution does not exist.

8.1.3.4 FR-950 Problems

Extensive use was made of FR-950 analog recordings of radar and beacon video during the data collection for the beacon performance analysis. Evidence showing that the use of FR-950 recordings may affect the results obtained was documented. Two important observations were made:

1) Differences in target report data and associated anomalies exist between CD record tapes made from real time beacon video and CD record tape made from analog readings of the real time beacon video.

2) CD output may be different when the same FR-950 tape is played through the CD at different times.

The problems were observed in three ways: the CD-Record displays, the average number of discrete beacon code target reports per scan, and the range split rate. Also, there were two separate APL trips to NAFEC. Some of the observations involved playing results obtained from the same FR-950 played back on each of these trips to NAFEC. The CD record tapes considered are put into four groups. All CD records in a particular group were made from associated video sources (i.e., either real time beacon video or an FR-950 analog recording of the real time video).

Results of the discrete beacon code target reports per scan comparison will be presented first. The comparisons were made by organizing the CD record tapes into groups. An FR-950 recording is associated with each group and CD records in the group are either made from the FR-950 or the real time video used to make the FR-950. Four groups (I through IV) were considered. The relevant information is illustrated by Figure 8.4. Points representing each CD record tape being considered are plotted and lines connect those points representing CD record tapes in the same group. The horizontal axis represents time in the sense that points representing tapes within a group are plotted in the order that the tapes were made from left to right. In addition, those points to the left of the vertical axis represent CD records made on the first APL trip to NAFEC, while those to the right represent tapes made on the second APL trip to NAFEC. The vertical axis represents percentage change in the average number of discrete beacon code target reports per scan in percent, with a tic interval of 10%. In each group, the average number of discrete beacon code target reports per scan measured for the first CD record made in the group is used as a reference for that group. The reference value in each group is plotted as the leftmost point in that group with an arbitrary position along the vertical axis. The other tapes within the group are plotted from left to right in the order that they were made, and their position on the vertical axis is determined by the percent change in the per scan rate of the average number of discrete beacon code target reports per scan. Lines connecting the points representing tapes in the same group were then drawn. The CD record tape associated with each point is indicated. Also an R or F is associated with each point on the illustration. An R means the CD record was made by playing real time beacon video into the CD. An F means that FR-950 video was used to make the CD record tape. In groups II and IV, the first CD record (leftmost), was made with real time beacon video. The others in groups II and IV were each made from an FR-950 analog recording of the respective real time video. Groups I and III used only FR-950 data.

An example of interpretation of the illustration will help clarify the meaning. Consider Group I on Figure 8.4. The first CD record made in this group was RUN 001, and the F means it was made from an FR-950 recording. The average number of discrete beacon code targets per scan for this tape was 98 (this is determined from Table 8.8). A point representing RUN 001 was plotted to the left of the vertical axis (since it was made on the first APL trip to NAFEC) with an arbitrary position along the vertical axis. The other tape in the group, CDR-804, was made from the same FR-950 as RUN 001 on the second trip. It had an average number of discrete beacon code targets per scan of 80 (from Table 8.8) which is about 18 percent below 98. The point, along the vertical axis for CDR-805 is plotted 18% below the position of RUN 001. Furthermore, it is to the right of the vertical axis because it was made on the second APL trip. The line is connecting the two points because they are of the same group.

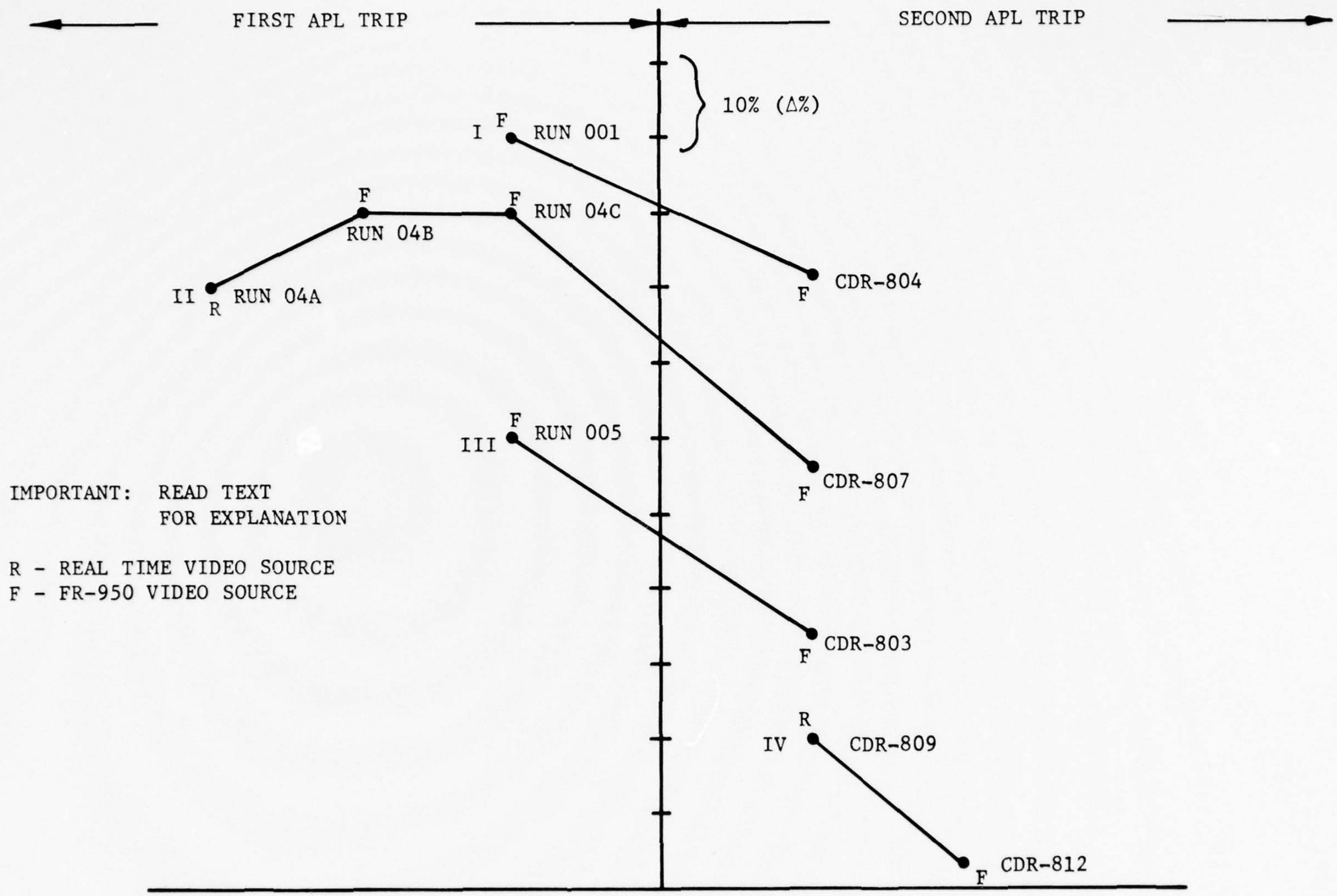


FIGURE 8.4

PERCENT CHANGE IN REPORTS PER SCAN

Figure 8.4 is very useful for visualizing the general trends in the data, which is its purpose. First, results made only on the same APL trip to NAFEC will be discussed. Groups II and IV are the only ones with more than one CD record made on the same trip (Group II the first trip, Group IV the second trip). As Group I shows, on the first trip the average number of targets per scan obtained from the FR-950 video (RUN 04B and RUN 04C) was higher than that obtained from the real time video (RUN 04A). Furthermore, the FR-950 results were the same for RUN 04B and RUN 04C. Thus the number went up from the real time value when the FR-950 was used, and the FR-950 result was repeatable. Next, Group IV shows the opposite. The number obtained from the FR-950 results went down.

Now compare results between the first APL trip and the second APL trip. For Groups I through IV, the value obtained from FR-950 data on the second trip was always lower than the first trip.

A tentative explanation is proposed to explain what is shown by Figure 8.4. Assume that some unknown but variable parameter affecting the video playback process exists. On the first trip, this parameter was set such that the playback resulted in more targets per scan than the real time video. On the second trip, it was set so that the FR-950 playback resulted in fewer targets per scan. The parameter is not known, but could be something as simple as playback gain on the FR-950 recorder.

The beacon reports from associated CD records in Groups II and IV were compared using the CD record display to determine the nature of the difference between real time results and FR-950 results. In the case of Group II, the extra reports appearing from the FR-950 results on RUN 04B and RUN 04C were clustered in the same location but it could not be determined that they formed tracks*. They may well have been false hits. For Group IV, the missing reports from the FR-950 result on CDR-810 appeared to be part of tracks. This might be explained by a different FR-950 playback gain setting. A high setting resulted in extra noise hits in Group II and a low setting resulted in a loss of reports on tracks in Group IV. This is purely conjecture, however, and is not to be construed as a conclusion that the unknown parameters was video playback gain. The point is that some variable parameter exists and it should be found so that its impact on the reliability of FR-950 video can be assessed.

Figure 8.5 is a similar illustration for the percent changes in the measured range split rate for Groups I, II and IV. The data was not available for Group III. The data used was obtained from Table 8.11. On the first APL trip, for Group II, the range split rate for the FR-950 results was lower than the real time results but at least repeatable for the FR-950 results.

*That is, visually the reports did not correlate with other reports from scan to scan.

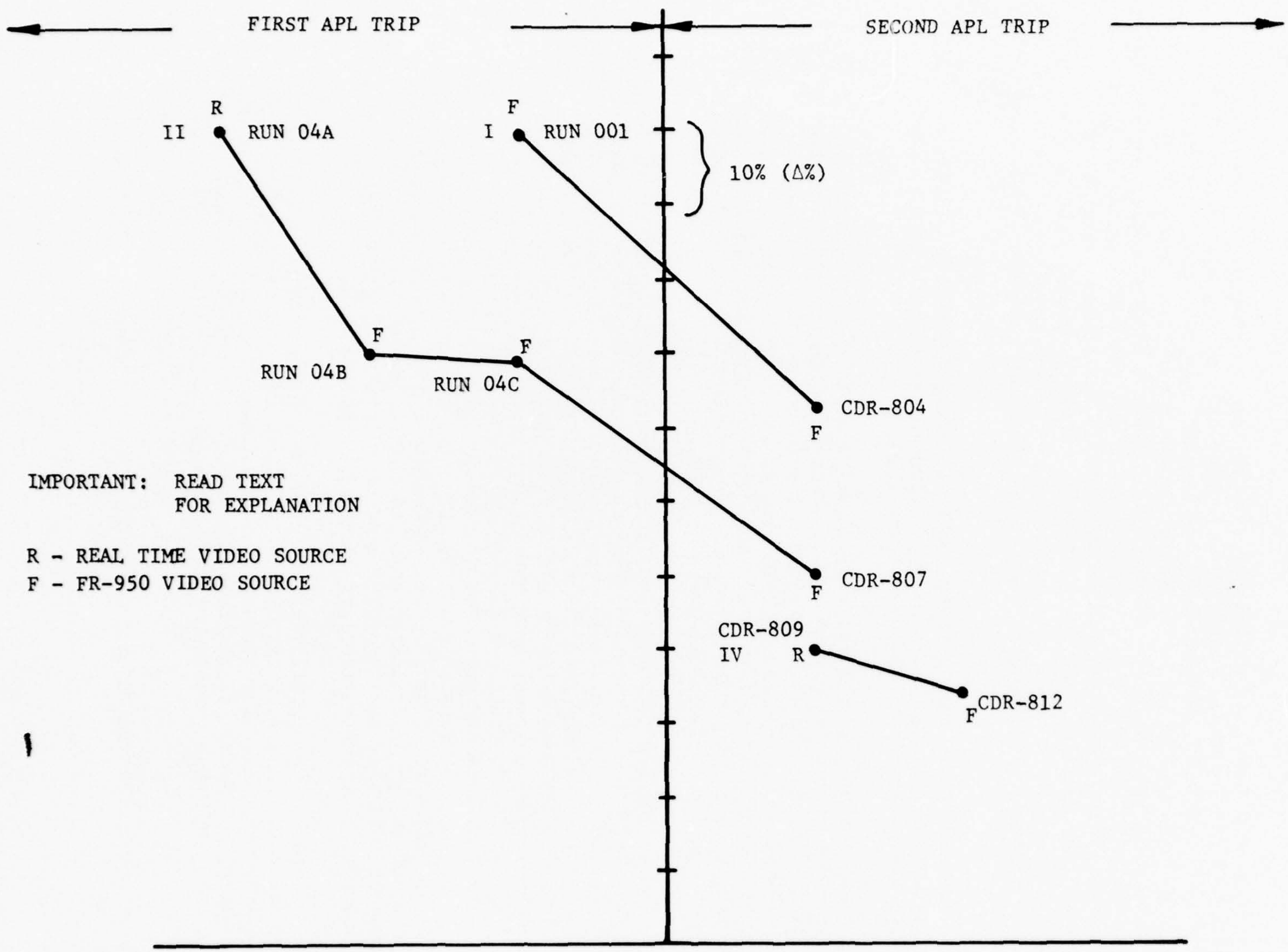


FIGURE 8.5

PERCENT CHANGE IN RANGE SPLIT RATE

The overall conclusion about the use of FR-950 tapes is that the target report data emanating from the CD when FR-950 video is inputted is not identical to that which was produced when the corresponding real time video was used to make the tapes. This is significant because the analysis of data obtained from FR-950 tapes is used ultimately to evaluate the CD performance at operational sites where real time video, of course, is used. It is recommended that the cause of the different results be isolated so that the impact on future analyses using FR-950 beacon video can be assessed.

8.1.3.5 Reply Analysis Anomalies

The primary objective of the reply analysis task was to consider the beacon replies corresponding to isolated examples of the problems identified for further investigation during the analysis of beacon reports. The investigation was suspended before this effort could be completed. Nonetheless, some interesting observations were made. The observations discussed here are in addition to those discussed elseqhere in connection with specifically identified beacon report anomalies.

One of the important aspects considered during the analysis of the beacon replies was that of proper CD centroiding. When a group of replies and their associated CD reports are displayed by the AI Mode 2 tape display system, the report appears to be slightly higher in azimuth than the eyeballed center of the replies. The centroiding algorithm that the CD is supposed to use was applied to the beacon reply data to compute the centroid azimuth. The results, for normal cases, were found to agree with the azimuth determined by the CD. Therefore the apparent slight positive azimuth offset of the report from the halfway point between the replies comprising the report is normal. Further, the offset was given theoretical consideration. It was determined that, for the Elwood CD, the beacon report centroid will be about 9 ACP's (0.79°) higher in azimuth than the point halfway between the first and last replies comprising the report for normal targets when the CD properly centroids beacon replies.

The remainder of what is presented here concerns cases where applying the CD centroiding algorithm to a group of replies does not result in the same report or reports that the CD produced. The first example concerns a range split. A pair of beacon target reports occurring with a range split configuration; i.e., 0.125 nmi apart in range and less than 3° in azimuth separation, was found in the target report data and the corresponding replies were examined. The replies had two important features: 1) they were all reported by the AI at the same range, and 2) there was no fade in the replies such that a trailing edge, followed by a leading edge could be declared. Since all the replies were at the same range, they should have all gone into the same range cell and generated only one target report. Yet the CD produced two reports apparently in adjacent range cells. The only simple explanation is that although the AI interpreter said the replies were at the same range, the CD put them in different range cells. This is a reasonable explanation because the AI reports the range of the replies as soon as the brackets are detected while the CD is storing the hits in memory cells and is constrained to memory read/write cycle times. Several range splits were examined. There were no range splits examined with enough replies at two different ranges to result in a report being declared in two adjacent range cells based on the AI reply ranges.

The next example is far more difficult to explain. In this case, two replies were reported by the CD at the same range on the same sweep. This is unusual because the CD can only process one reply per range cell per sweep. In view of the range uncertainty problem presented above, it might be said that these two replies were really in different range cells even though the AI said they were at the same range. However, another important fact exists. Both of the replies that were at the same range on the same sweep are required, in this case, to reach the target leading edge. Thus they were both apparently processed in the same range cell. This type of anomaly was documented only once. It was observed to occur at least one other time, but its frequency is not really known. It may, for example, be a result of a CD timing failure or an intermittent AI failure.

Another case was examined in which the CD did not properly centroid the replies. The range uncertainty theory can explain this problem. When the CD centroiding algorithm is applied to the replies, the computed target report leading edge is several sweeps before the CD actually declared it. This could be because some of the replies that appear to be at the same range in the AI data were put in a different range cell by the CD and consequently not used to declare the leading edge threshold.

The next anomaly occurred when two target reports were generated even though there are not enough replies to generate the two. Two target reports in a range split configuration were examined. They will be called reports A and B. All the associated replies were at the same range. When a leading edge threshold was computed from the reply data by applying the CD algorithm, it corresponded to the leading edge threshold that the CD declared for report B. Thus six replies were used to declare report B in a range cell. On the very next Mode 3/A sweep, the CD declared a target leading edge for report A in an adjacent range cell. Since the first six Mode 3/A replies were already used to declare report B, there was only one reply in the adjacent range cell, yet report A was declared. This implies, perhaps, that the replies are simultaneously getting processed into two adjacent range cells. This has never been conclusively shown, however.

The last example was an azimuth split. This was a fairly normal group of replies and it is obvious that, in this case, the azimuth split was caused by missing replies preceded and followed by non-missing replies.

The conclusions from this are several. First, there is definitely some sort of range difference between the AI reply range and the CD ranging. Second, there were other, more difficult anomalies present which may be freaks but might also be the symptom of a serious CD processing problem.

For the range uncertainty problem, it would be interesting to take the recorded replies and play them into a computer program that simulates CD processing. The resulting reports could then be analyzed to determine

what, if any, anomalies are introduced by the CD. The purpose here is not to replace the CD but rather to use computer aids to study its behavior and isolate trouble spots so that they could be improved upon.

For the other anomalies, it is recommended that their frequency first be determined to see if they are freaks or actually representative of real CD problems. Appropriate action will be indicated by the results of additional analysis.

8.1.3.6 VQR Results

The quantized video signal intensity from a replying transponder was displayed as a function of range and azimuth. The individual replies and pulses within the replies were easily discernable from the illustration. It was shown that the mode interlace, range jitter, and garbling conditions could be predicted from the quantized video data. Next, single sweeps from a Mode C reply and Mode 3/A reply were each displayed. From these, pulse shape, beacon code, and Mode C altitude were extracted. Finally, the associated replies as recorded on the AI Mode 2 tape were located and compared.

The information extracted from the VQR data agreed very satisfactorily with the Mode 2 data.

In addition to the usefulness of the VQR data as utilized by the Laboratory, two important conclusions were made. The first one concerns the range jitter problem. Throughout the beacon analyses, one of the important topics of discussion has been that of range splits. The proposed mechanism for generation of range splits is related to range jitter in the ATCRBS and it has been proposed by the FAA and perhaps others, that CD modification be made to allow detection of transponder replies with more accuracy to eliminate or reduce range jitter and associated range splits. The theoretical analysis described in Section 4.2 shows that although the CD is a source of range jitter, other significant jitter sources exist in ATCRBS, which will result in reply range jitter prior to CD processing. An example of VQR data shows clearly that, in the case of the example presented, the range variations between successive replies at the video level before CD processing was at least 100 nsec and possibly greater. This was only one example and a more thorough investigation should be made. The investigation was not completed by the Laboratory because the effort on this task was suspended. With jitter of this magnitude prior to CD processing, it makes little sense to attempt to detect replies in the CD to within only a few nanoseconds. Elimination of range splits will involve more sophisticated processing of reply data, such as hit placement techniques or sliding window merging.

The second conclusion was that the VQR window was not correctly placed. While the recorded azimuth and range for VQR window agreed with the requested numbers, the actual placement of the window was correct in range but 127 ACP's behind the desired azimuthal placement relative to the AI Mode 2 reply data. Since the AI Mode 2 reply data agrees in azimuth with the target report azimuths outputted by the CD, the azimuthal displacement is in the VQR process. The actual cause is unknown, but may be a result of the -127 ACP preset to the azimuth counter in the CD upon the occurrence of the azimuth reference pulse. In any event, the cause must be found before beacon video corresponding to preselected replies can be quantized.

8.2 NAFEC FACILITIES AND DATA COLLECTION

8.2.1 Introduction

In order to collect the data necessary to perform the beacon performance analysis of the CD, the Laboratory made extensive use of the NAFEC facility at Atlantic City, New Jersey. All beacon video used was processed by the CD at Elwood, N. J. and target report data from this CD was transmitted via the narrowband modem lines to the Air Route Traffic Control Center (ARTCC) at NAFEC, Atlantic City, where the CD-Record tapes of target reports were made. The Elwood CD was used because it is equipped with a special minicomputer, called an Auxiliary Interpreter (AI), which allows real time extraction of beacon reply information.

In this subsection, the NAFEC facility used for data collection is described in detail. A general data collection process is described. Finally, the actual data collected is listed. In some cases, problems with the data collection became evident. These problems could potentially have an impact on future investigations, as they may affect data quality. Therefore, the problems of this significance are presented here and recommendations concerning them are made.

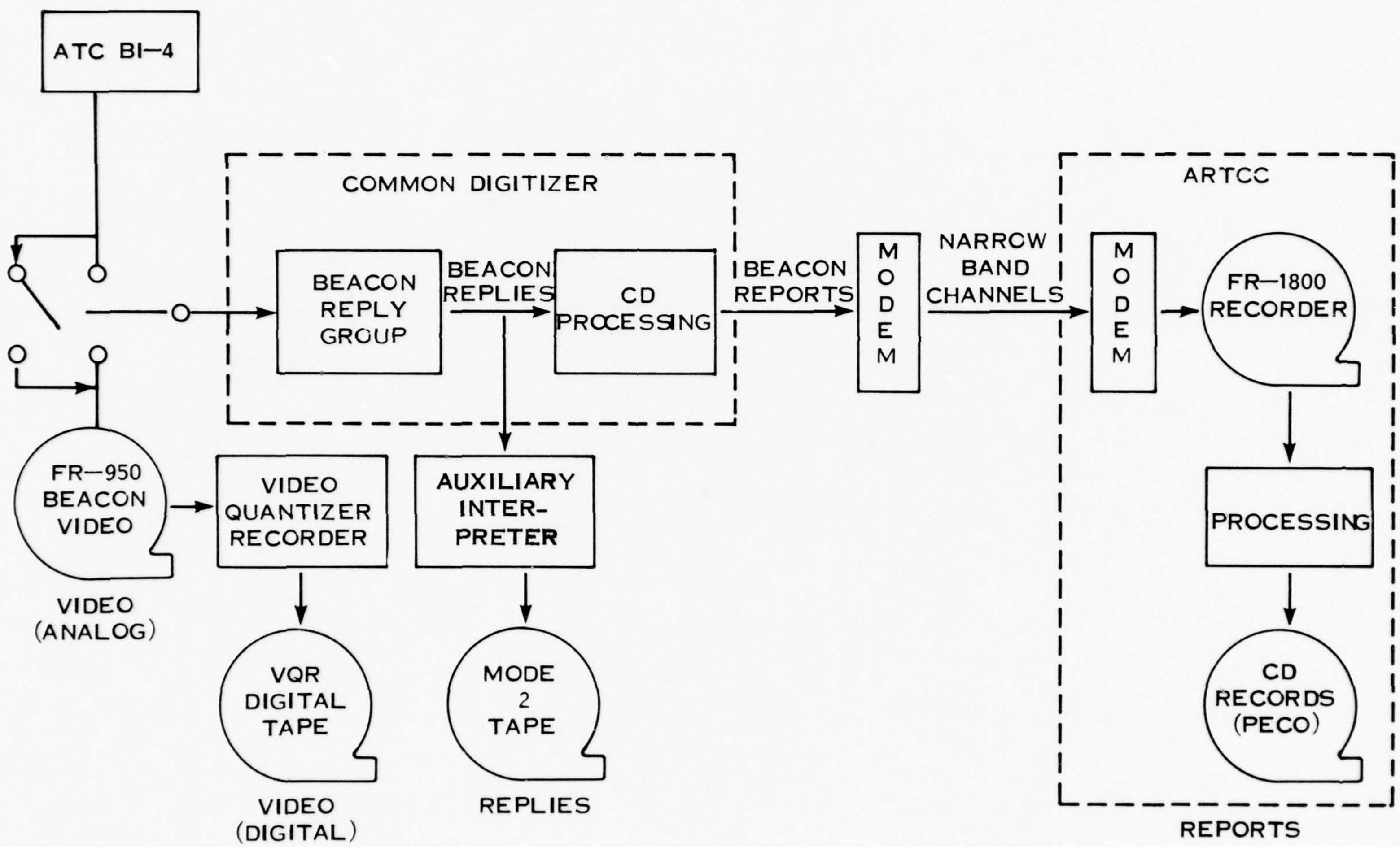
8.2.2 NAFEC Facility

Figure 8.6 is a block diagram showing the relevant components at NAFEC used to implement the data collection. The Air Traffic Control Beacon Interrogator-3 (ATC BI-3), FR-950 recorder, Common Digitizer (CD), and Auxiliary Interpreter (D-machine or AI) are located at the ARSR-7 site at Elwood. The ARTCC is located at NAFEC in Atlantic City. The Video Quantizer Recorder (VQR) machine is located at the ASR-5 site. The Elwood CD is a special "Enhanced Common Digitizer" which is equipped with an Auxiliary Interpreter (AI). The AI performs several functions, including interaction with the CD during radar processing (see Section 5.2). Figure 8.7 is a block diagram of the hookup of the AI to the CD. Blocks and connections shown in solid lines are CD equipment while AI equipment is shown in broken lines. The primary function of the AI during collection of data for the beacon performance analysis was the extraction of beacon reply information.

The video input to the common digitizer can come from either of two sources. First, the ATC BI-3 may be turned on, and real time video from its receiver inputted to the CD. The alternate video source is the FR-950 analog recorder. Whenever real time video is being used, the option of making a simultaneous FR-950 analog recording of the video exists. The FR-950 tapes have sufficient capacity to accommodate two video channels, and these are normally beacon video and log normal radar video.

FIGURE 8.6

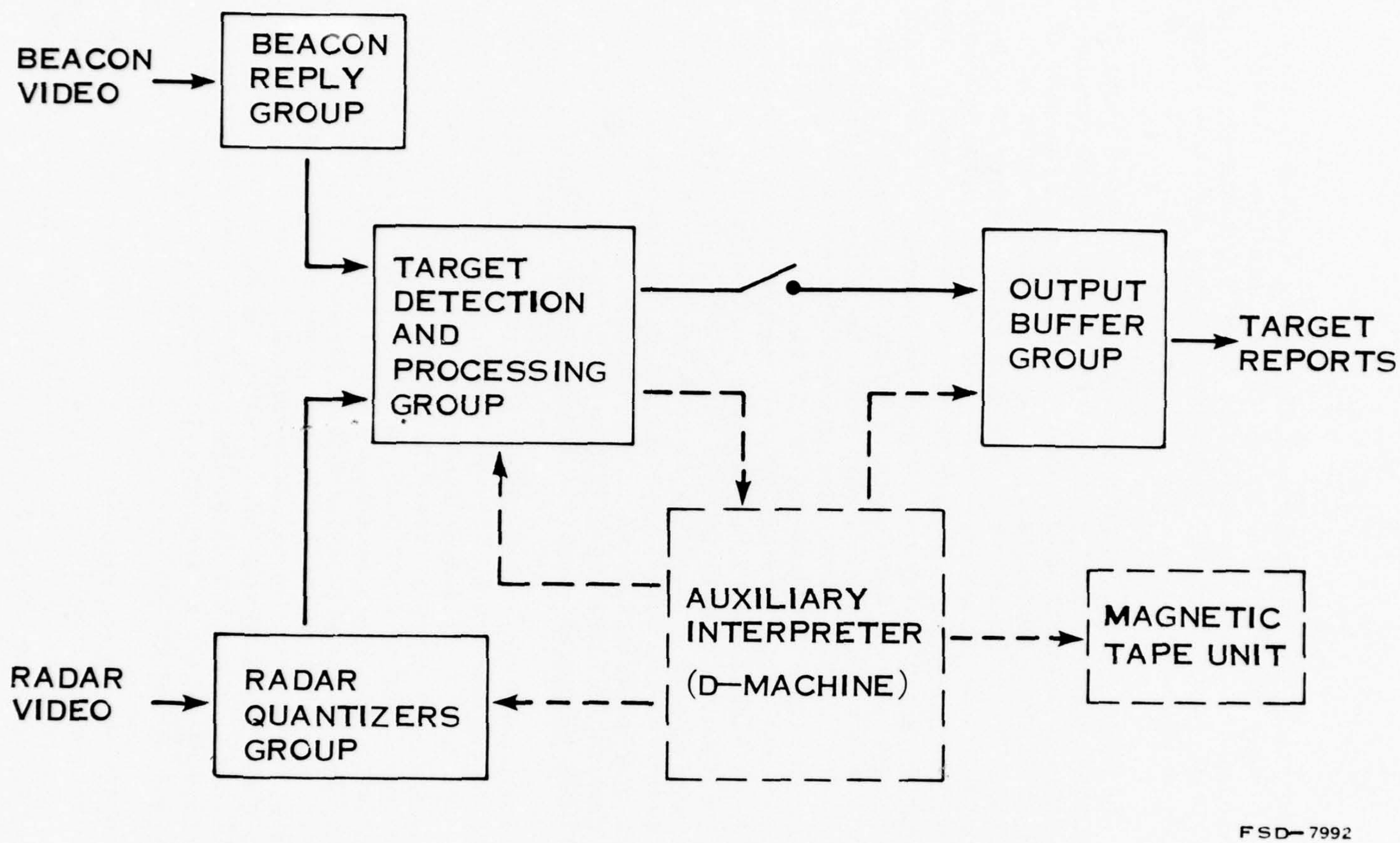
BEACON PROCESSING DATA COLLECTION



FSD-8226 A

FIGURE 8.7

ENHANCED COMMON DIGITIZER



When real time video is used the CD can receive beacon video, log normal radar video and MTI radar video. At any one time, the CD processes the beacon video and one of the two available radar video signals. A crossover range is defined, below which MTI video is processed and above which log normal video is used.

The video signals, both radar and beacon, may be quantized by the VQR machine which produces a digital tape of the video sampled within specified range and azimuth boundaries. Limitations on the size of memory within the VQR machine restricts these boundaries to a window approximately 8 nmi by 147 ACP's in the analysis of beacon video. Since the VQR machine is not located at the Elwood site, the video being inputted to the Elwood CD cannot be simultaneously inputted to the VQR machine as well. Thus, if a VQR tape of a specified region of range and azimuth on an FR-950 is required, the FR-950 tape must be taken to the VQR location to produce the VQR tape. As a consequence, when real time video is the data source into the CD, the only way that a VQR tape can be obtained is by making an FR-950 tape and then making a VQR from the FR-950 tape. In theory, this should present no problem. In practice, however, target report data generated using FR-950 data has been shown to be different from target report data generated from the real time video used to make the FR-950 tape. This may be an indication that the FR-950 process in some way distorts the video and thus the VQR tapes made from the FR-950 tape may not be representative of the real time video. The problem is discussed in more detail in later subsections, but is mentioned here to indicate the significance of the limitation that real time video at Elwood cannot be quantized directly by the VQR machine.

The beacon video into the CD is first range integrated by the beacon reply group to produce beacon hits or beacon replies. The AI extracts, in real time, the beacon replies. Beacon reply data is accumulated in AI buffers until full, and then a reply record is written on a digital magnetic tape. The AI has the capability of functioning in other modes besides extraction of beacon replies. The tapes containing beacon replies are made when the AI operates in Mode 2, and are called Mode 2 tapes. The replies in the CD are then further processed to produce beacon target reports. These reports, in digital form, are encoded in an analog signal for transmission over the narrowband MODEM lines to the ARTCC. Here, the analog signal is recorded on an FR-1800 tape. At a later time, the FR-1800 can be played through the IBM 9020 computer system at the ARTCC to produce the digital recordings of target reports called CD-Records.

While the beacon processing has been primarily addressed here, the CD-Records will also contain radar target reports if radar video was inputted to the CD. In addition to the beacon replies, both beacon and radar target report data may also be recorded on the AI Mode 2 tapes.

Another piece of equipment at the Elwood facility (not shown in Figure 8.6, is the PPI-RAPPI display console. This display can be used to look at raw video, in-process target reports and completed target reports in the CD.

A time code generator is also provided at the Elwood facility for generating a time code that is written on the FR-950 tape during recording and for decoding and displaying FR-950 during playback of the FR-950. The PPI-RAPPI console also contains a real time clock which is usually set to the time of day. The time displayed on the console is synchronized with a clock at the ARTCC which puts time on the FR-1800 tape. Time references exist therefore, for FR-950 tapes and CD record tape (made from the FR-1800). At the times which the data for this analysis was collected, no time information could be recorded on the AI Mode 2 tapes.

8.2.3 Description of Data Collection Procedures

The collections of the FR-950 tapes, Mode 2 tapes, FR-1800 tapes (from which the CD records are made) were made in data collection runs lasting about twenty minutes each. The data collection runs were made using the NAFEC facilities depicted in Figure 8.6 which should be referenced as necessary during the following discussion. The actual tapes being recorded during any given run depended upon the data requirements which were being satisfied by that run and the availability and operational status of the associated equipment. Thus some data collection runs were made without Mode 2 recording and some collections were made using real time video in which no FR-950 tape of the video was made. The data collection process will be described for the general case in which all tapes would be made.

Basically, a data collection run consists of inputting radar and beacon video from either the ATC BI-3 receiver or an FR-950 analog recording of video to the CD and collecting the required tapes. Before each run, the system configuration, parameter settings, radar-beacon range alignment, and time correlation between tapes to be collected must be considered. This section describes these considerations in more detail.

The CD records were not made during the data collection run. Instead, the FR-1800 tapes which are made during the data collection run, were played through the IBM 9020 computer system at a convenient time to produce the CD records of target report data.

The digital VQR tapes of beacon video also were not made during the data collection run. After analysis of collected report and reply data, range-azimuth windows were specified for selected FR-950 tapes. The VQR machine was then used to quantize the video occurring within the designated windows and produce a VQR tape of these selected regions.

Finally, several problems with the data collection became evident either during the actual data runs or as a result of analysis of the data collected. Some of these problems may have an impact on fugure investigations which involve a similar data collection and these problems are presented here along with recommendations concerning them. In cases where analysis of the data was required to discover the problem, a brief discussion will appear here along with a reference to the appropriate section describing the analysis.

System configuration considerations for the data collection run involve the selection of video source and certain wirestrap selectable options on the AI. The video could come from the FR-950 video recorder or the ATC BI-3 and the ARSR-2 search radar could be turned on and real time video used. Also it was desired that beacon run length, beacon target reports and search radar target reports be put on the Mode 2 tapes; however, because of incorrect wirestrap selections, some Mode 2 tapes were made without this data. Some FR-950 tapes made at sites other than Elwood (St. Louis and Paso Robles) were used as a video source. All sites, including Elwood, were equipped with ARSR-2 search radars and ATC BI-3 beacon equipment.

Numerous parameter settings were considered. For all the tapes made the following CD parameters were constant:

$$T_L = 6$$
$$T_L - T_T = 4$$
$$T_V = 5$$

Blanking ranges must also be set in the CD. The CD may be inhibited from processing radar video in certain regions. This is called blanking, and up to three blanked regions may be defined by presetting the start and stop ranges and azimuths for each region in the CD. Blanking is normally done to prevent overloading CD processing with heavy search radar clutter returns. Since the FR-950 tapes chosen for playback had only normal or log-normal video, there was considerable close-in clutter. Blanking was appropriately set to eliminate this heavy clutter. When operating the CD with the radar in real time, MTI video is also available. A crossover range, below which MTI video only is processed, and above log-normal video is processed, may be defined for three contiguous sectors. In theory, the MTI video should reduce the close-in clutter to an acceptable level. Heavy clutter regions may still exist and blanking would be used for these regions. The crossover ranges normally used at the Elwood site are given in Table 8.1.

TABLE 8.1

MTI - LOG NORMAL CROSSOVER RANGE

	Azimuth Limits (deg)	Crossover Range (nmi)
Sector 1	337° - 118°	28
Sector 2	118° - 247°	22
Sector 3	247° - 337°	24

Blanking ranges may also be set for the beacon video processing. While such blanking was not requested by the Laboratory, apparently beacon video processing was blanked for some of the runs above and below some ranges. The inadvertant blanking had little or no impact on the quality and useability of the data collected.

The beacon interrogation mode interlace was also varied during some of the runs. The ATC BI-3 can interrogate three modes: 3/A, C and 2. These may be interlaced in several fixed selectable patterns by the interrogator. Such patterns as

3/A only,
3/A, C, 2, and
3/A, 3/A, C

are available. When real time video is being used, the interlace pattern must be selected. When FR-950 video is used the interlace is determined by the settings used when the FR-950 tape was made and is interpreted from the FR-950 tape by the CD. In one case, an FR-950 tape at Elwood had Mode D interrogations. This mode is an experimental mode and is simply ignored by the CD. The pulse repetition frequency (prf) was 360 per second and scan rate was 9.6 seconds per scan for all Elwood video and the St. Louis video but was 240 per second and 12 seconds per scan for Paso Robles.

Radar-beacon range alignment refers to the offset that may exist between a radar report and the corresponding beacon report. This alignment is adjusted by properly aligning the radar and beacon video into the CD. When the video signals are not properly aligned the effect is observed from the target reports. Alignment between radar and beacon reports out of the CD varied from tape to tape. Four different alignments existed.

1. Properly aligned.

2. A modification called the "Cardon-mod" has been installed on the CD at Elwood and probably most CD's in the field. This modification introduces an additional delay in the search radar processing, so that incoming video to the CD must be adjusted to compensate. Some FR-950 tapes used in data collection were made before the Cardon-mod was installed and the radar-beacon alignment on these is adjusted for the post Cardon-mod CD. This causes the radar and beacon reports to be misaligned when played through the CD with the modification.

3. The CD has an option which offsets the beacon target reports by + 1/2 nmi.

4. CD timing is adjusted to properly align the radar and beacon video properly at each site. The alignment for one site is not necessarily the same as for another site. Thus, tapes not made at the Elwood site, but played through the Elwood CD will be misaligned.

A system was established for assuring time correlation between FR-950 tapes, Mode 2 tapes and CD record tapes. A clock on the PPI-RAPPI console at Elwood is set to the time of day and synchronized with a clock at the NAFEC ARTCC which puts time on the FR-1800 tapes. This time (the time of day of the data run) is recorded on both the FR-1800 tapes and CD record tapes. When an FR-950 tape is used as the source of video, the time of day when the FR-950 tape was made is displayed by the time code generator display on the FR-950 equipment rack. If real time video is being used, the time code generator is synchronized with the clock on PPI-RAPPI console which is displaying the time of day of the data collection run. Thus if an FR-950 tape is made during a data collection run using real time video, it will have the time of day of the data collection run recorded on it.

At the beginning of the data collection run, both the time displayed by the time code generator on the FR-950 rack and the clock on the PPI-RAPPI console are recorded. This provides a time link between the FR-950 tape, the FR-1800 tape and the CD record.

Time is not recorded on the Mode 2 tapes. In order to provide a time link with the Mode 2 tape, the time displayed by the FR-950 equipment when the first azimuth reference pulse occurs after the start times recorded for the FR-950 and FR-1800 at the beginning of the data collection run, which starts the Auxiliary Interpreter processing, is recorded. This makes it possible to time correlate the data on the FR-950 and CD records with the Auxiliary Interpreter tapes, since the time of the first AI record is then known. The link with the Mode 2 tape is determined from the start time of the first record and the scan rate of the antenna. To determine the time of a given

report/reply set on the Mode 2 tape, the time of the first record is added to the product of the scan rate (expressed in seconds per scan) and the elapsed scans from the first record to the report/reply set of interest. This is, of course, approximate, but is sufficient to correlate data on the Mode 2 tape with data from the FR-950 tape and CD record tape.

After analysis of the target report data and reply data, range-azimuth windows can be specified for selected FR-950 tapes. These specifications are submitted to FAA personnel at NAFEC, who then use the VQR machine to produce digital VQR tapes of the analog FR-950 video in the designated windows. Laboratory personnel were not present for the production of the VQR tapes.

8.2.4 Discussion of Collected Data

This section presents the actual data collected. Two trips to the Elwood ARSR-2 site were made by Laboratory personnel for the purpose of collecting data. The purpose of the first trip was to review the FR-950 tape library and select some FR-950 tapes to be used as a data base. In addition, real time video was used to make an FR-950 tape. Mode 2 reply data was not recorded because the AI was not available at the time. The purpose of the second trip was to play the selected FR-950 tape back through the CD to produce Mode 2 reply tapes and, in addition, collect some new data as well. Some problems with the Mode 2 recording were discovered and will be discussed. After these two data collections, a sample VQR tape quantizing several windows was requested. Problems existing with VQR window placement existed. After the Mode 2 recording problems were resolved, the Laboratory requested that a data collection run be done by NAFEC personnel so that a sample Mode 2 tape could be made. This tape and associated CD record tape were received by the Laboratory. Range-azimuth windows were specified for the FR-950 tape used to make the sample reply and CD record tapes and the corresponding VQR tape was received. Problems were apparent with all the VQR tapes and are discussed here.

8.2.4.1 First APL Trip to Elwood

On February 20-21, 1975, Laboratory personnel traveled to Elwood, N.J. in order to review the FR-950 tape library of beacon video recordings. The primary purpose for this trip was to play several FR-950 recordings through the CD and obtain CD record tapes of the resulting target reports. A list of the tapes, parameter settings, start and stop times of the tapes, and specific notes taken on items peculiar to each tape follows. It should be noted that the cooperation and support of NAFEC personnel in this exercise was excellent.

Table 8.2 is a list of the data recorded on the first APL trip. The FR-950 tape made from this real time data run, 4A, was played through the CD twice in runs 4B and 4C. This tape is referred to as ELWD #1, 2/20/75. Following is a list of comments noted for each entry in the table.

TABLE 8.2

DATA LISTING

TAPE	DATA	INTERLACE	BLANKING RANGE (NMI)	CROSS OVER BOUNDARIES	OFFSET*	SCAN RATE (SEC/SCAN)	PRF (PER SEC)	FR-950 START TIME	FR-1800 START TIME	FR-1800 END TIME	DATE OF RUN	RUN NO.
ELWD #1 2/3/75	LOG/BCN	3/A,3/A,C	below 25	NA	1	10	360	002100	095101	101500	2/20/75	1
ELWD #8 1/30/74	LOG/BCN	3/A,D**	below 40	NA	1	10	360	174600	105801	111800	2/20/75	2
ELWD #1 4/4/73	LOG/BCN	3/A,3/A,C	below 32	NA	2	10	360	150700	131907	134209	2/20/75	3
REAL TIME	LOG/MTI/ BCN	3/A,3/A,C	NONE	See Table 1	3	10	360	143208	143208	145710	2/20/75	4A
ELWD #1 2/20/75	LOG/BCN	3/A,3/A,C	below 32	NA	3	10	360	143400	151856	153859	2/20/75	4B
ELWD #1 2/20/75	LOG/BCN	3/A,3/A,C	below 32	NA	3	10	360	143400	154239	155600	2/20/75	4C
PASO ROBLES #5 4/14/74	LOG/BCN	3/A,3/A,C	below 64	NA	4	12	240	213200	101224	104123	2/21/75	5
ST LOUIS #3 6/15/73	NORMAL/ BCN	3/A,C	ABOVE 208 NMI	NA	4	10	360	1_2700	111735	114305	2/21/75	6

*OFFSETS:
1. NO OFFSET
2. OFFSET CAUSED BY CARDON MOD
3. BEACON OFFSET + 1/2 NMI
4. OFFSET CAUSED BY USING A TAPE FROM A DIFFERENT SITE

**MODE D IGNORED BY CD

NA = NOT APPLICABLE

Run #1

Some breaks in what appeared to be single beacon targets on raw video PPI occurred. On all tapes recorded at Elwood, N.J. there are considerably less targets in the southeast sector. This area is over the Atlantic Ocean and has been designated as a warning area; therefore, few aircraft fly in this region.

Run #2

The interlace pattern for Run #2 is Mode 3/A, D. Mode D is a special experimental type of code and is ignored by the CD.

The 32 mile blanking was not in effect for a small sector around 0° during the first part of Run #2. During Runs #1 and #2 there was no switching to the fast loop of the improved quantizer. This problem was eliminated in the following runs.

Run #3

This data contained weather clutter in the southern and southeastern areas. The data in this run has been rotated clockwise in azimuth about 90°. The Atlantic Ocean is toward the southwest.

Run #4A

Run 4A is the real time run.

Run #4B

Playback of real time tape made in Run #4A. During part of the run around 152500 the beacon mode triggering was faulty, causing targets to be improperly processed. Several scans (about 12) of report data were lost.

Run #4C

FR-1800 ran out for last ~ 8 minutes of this run.

Run #5

A range alarm occurred at first part of tape. This indicates a missed radar trigger or a radar grigger detected outside of expected limits. It means that for that particular sweep the ranging could be incorrect. Also there was a question about the correctness of the time synchronization for this run. The end time for the FR-950 did not appear to correlate properly with the end time for the FR-1800.

There existed extensive land clutter on this FR-950 tape, particularly in the northeast out to approximately 120 nmi. A large number of false search targets were generated in this area. The density of search targets outside of this area was lower than on previous runs. There existed a continuous ring of beacon replies at 200 nmi which were artificially inserted for test purposes. The fruit rate on this tape appeared lower than on tapes recorded at Elwood.

Run #6

From the beginning of the run to about 11:23:55 sector blanking from 348° - 39° out to 64 nmi was inadvertantly set. There also appeared to be several azimuth jumps in the playback of the tape.

The search data on this run is very poor. Normal search was the type of video recorded. The improved quantizer operates more efficiently on log normal. Because of this there are a great number of false search target reports.

8.2.4.2 Second APL Trip

During the week of July 7-11, 1975, APL engineers traveled to the NAFEC facility at Elwood, N.J. to run CD tests and obtain data tapes. On July 10-11, CD records and Auxiliary Interpreter Mode 2 tapes were recorded for use in the beacon analysis.

Table 8.3 lists the real time runs and tapes made. The scan rate and PRF were constant for the real time data taken at Elwood. Due to improper adjustment, the search and beacon videos were not properly time aligned and a constant misalignment exists for all the real time data. The column in the table called D-tape refers to Auxiliary Interpreter Mode 2 tapes, which are also known as D-machine Mode 2 tapes. The MTI-log normal radar video crossover ranges are given by Table 8.1.

Table 8.4 is a list of the tapes taken using FR-950 video. For each of these runs one D-tape was made. Since only log-normal search video is available from the FR-950 tape, the crossover ranges of Table 8.1 do not apply. Instead, blanking was used for search targets less than 32 nmi. When the Auxiliary Interpreter is off target reports should not go over the MODEM lines. However, it was observed that reports went over anyway. The following is a list of summarized comments from the notes taken during the recordings.

TABLE 8.3

REAL TIME DATA

RUN	MODE INTERLACE	FR-1800 TIME		TAPES MADE		FR-950 TAPE			D-TAPE				CD RECORD LABEL	DATE OF RUN
						TIME OF DAY			TIME OF DAY					
		START	STOP	FR-950	AI TAPE	START	STOP	LABEL	START	STOP	SEARCH REPORTS	LABEL		
9	3/A, 3/A, C	10:53:00	11:18:30	1	2	10:53:06	11:15:15	Elwd. #1 7/11/75	10:53:04	11:03:20	YES	D-807	CDR-809	7/11/75
									11:07:07	11:18:30	YES	D-808		
10	3/A, C, 2	11:23:00	11:50:00	0	1	--	--	--	11:35:08	11:50:00	YES	D-809	CDR-810	7/11/75
11	3/A ONLY	13:00:00	13:15:00	0	1	--	--	--	13:08:00	13:15:00	YES	D-810	CDR-811	7/11/75

SITE: ELWOOD, N. J.
SCAN RATE: 9.6 SEC/SCAN
PRF: 360/SEC
SEARCH-BEACON ALIGNMENT: CONSTANT MISALIGNMENT

TABLE 8.4

DATA COLLECTED USING FR-950 VIDEO

										AI TAPE					
						FR-950 TIME		FR-1800 TIME		FR-950 TIME					
RUN	FR-950 SOURCE	DATA	INTERLACE	SEC/ SCAN	PRF	START	STOP	START	STOP	START	STOP	SEARCH	LABEL	CD RECORD LABEL	DATE OF RUN
3	PasoRobles #5 4/14/75	LOG/BCN	3/A, 3/A, C	12	240	21:32:00	21:52:00	13:34:39	13:54:39	21:32:05	21:52:00	YES	D-801	CDR-803	7/10/75
4	Elwd #1 2/3/75	LOG/BCN	3/A, 3/A, C	9.6	360	00:21:00	00:41:00	14:33:21	14:53:21	00:21:04	00:41:00	YES	D-802	CDR-804	7/10/75
5	Elwd #8 1/30/75	LOG/BCN	3/A, D	9.6	360	17:46:00	18:06:00	15:06:57	15:26:57	17:46:03	18:06:00	YES	D-803	CDR-805	7/10/75
6	Elwd #1 2/20/75	LOG/BCN	3/A, 3/A, C	9.6	360	14:34:00	14:39:12	15:48:12	15:53:00	14:34:09	14:39:12	YES	D-804	CDR-806	7/10/75
7	Elwd #1 2/20/75	LOG/BCN	3/A, 3/A, C	9.6	360	14:34:00	14:54:00	9:41:21	10:01:21	14:34:09	14:45:30	NO	D-805	CDR-807	7/11/75
8	Elwd #1 2/20/75	LOG/BCN	3/A, 3/A, C	9.6	360	14:54:00	14:57:00	10:01:21	10:04:21	14:54:0-	14:56:55	YES	D-806	CDR-808	7/11/75
12	Elwd #1 7/11/75	LOG/BCN	3/A, #/A, C	9.6	360	10:53:30	11:15:00	13:29:50	13:51:20	10:53:32	11:07:00	YES	D-811	CDR-812	7/11/75

SEARCH BLANKING: LESS THAN 32 NMI

Run #4

Azimuth and range alarms of the CD went off several times during this run.

Run #6

After a short time of what was thought to be normal tape movement for the Auxiliary Interpreter Mode 2 tape, the tape began to move much faster giving the appearance of run-away. The run was restarted with the same results. The run was terminated after 5 minutes.

Run #7

This was an attempt to repeat Run #6. The rapid Mode 2 recorder movement occurred again but the run was continued anyway.

Run #8

This run was made accidentally when the Auxiliary Interpreter processing was started on the wrong cue. The source was the same FR-950 tape used in Run #7 but the Mode 2 tape run away did not occur so the data was kept. CD records 805 and 806 will be on the same tape.

Run #9

This run was to start at 10:53 using real time video. However, the FR-950 wasn't started until about 10:53:06. At about 11:07:00 the Mode 2 tape speed increased to give a run away appearance. The run was continued to completion anyway.

Runs #10 and #11

No FR-950 tape was made for these runs. The Mode 2 recorder appeared normal.

Run #12

This run used the FR-950 of video from Run #9. In Run #9 the Mode 2 tape speed increased. It remained normal for Run #12.

8.2.4.3 Mode 2 Tape Recording Problems

During the data reduction, of the twelve AI Mode 2 tapes recorded, four of the tapes were found to be unreadable as a result of parity errors. Furthermore, it was found that run length reporting was not selected and beacon target report information was not being recorded. Similar parity error problems occurred during attempts to collect other AI recordings for other APL investigations.

8.2.4.4 First Sample VQR Tape of Beacon Video

After analysis of the above collected data was completed, a sample VQR tape of beacon video was requested on April 17, 1975. Four windows were requested. Table 8.5 lists the requested windows.

All beacon recordings were made from the same FR-950 tape, Elwood #1 2/20/75. The specific recording parameters follow:

Quantization: 6 bit

Sampling Rate: Every 1/128 nmi.

Packing Density in Core: Five 6-bit samples per 30 bit word.

TABLE 8.5

VQR WINDOWS

START RANGE	STOP RANGE	START AZIMUTH	STOP AZIMUTH	START TIME (hr:min:sec)	STOP TIME (hr:min:sec)
58 nmi	64 nmi	354°	6°	14:34:00	14:36:00
142 nmi	150 nmi	297°	309°	14:34:00	14:37:00
150 nmi	158 nmi	357°	4°	14:34:00	14:38:30
14 nmi	22 nmi	195°	207°	14:36:00	14:38:00

The requested windows contained beacon target reports with observed problems such as range splitting. Unfortunately, the actual windows quantized did not include the beacon video corresponding to these reports. A problem evidently exists as to the definition of the absolute references used to specify the range and azimuth limits of the desired window. The VQR tape was used to develop the VQR display system but was not used in the analysis. Another VQR tape was obtained later and used to further analyze the window placement problem.

8.2.4.5 NAFEC Data Collection Run

Because of the AI recording problems, it was decided to have NAFEC submit a set of sample tapes to the Laboratory for analysis. If these tapes did not exhibit severe problems, then the remainder of the required Mode 2 tapes could be collected. Following is the request submitted to NAFEC:

Run #1

CD Settings

1. $T_L = 6$
2. Sliding Window Size = 11
3. $T_L - T_T = 4$
4. $T_V = 5$
5. The beacon and radar reports are to be properly aligned.

"D" Machine

1. Enable run length reporting.
2. Put search and beacon reports on Mode 2 tape as well as replies for beacon data.

Beacon Interrogator

Use an interlace of 3/A, 3/A, C.

Procedure

Play real time Log-Normal search video and beacon video through the CD. The search video may be appropriately blanked below some range. Produce (a) a CD Record tape, (b) a Mode 2 Auxiliary Interpreter tape and (c) an FR-950 recording. Take twenty minutes of data or fill up the "D" machine tape, whichever is shorter.

After the request was submitted, it was discovered by NAFEC personnel that the radar and/or the beacon interrogator RF was interfering with the Mode 2 recording process, causing the AI recording parity errors, thus eliminating the possibility of a live data collection. Therefore NAFEC made the FR-950 tape first, then played it back through the CD with all RF equipment turned off to make the Mode 2 tape and FR-1800 tape. Following is a list of the tape designations for the tapes made:

FR-950 - APL #12-75
CD Record - 1/16/76 32
Mode 2 - 1/16/76 #1

The CD record and Mode 2 were received by the Laboratory. NAFEC is retaining the FR-950 for future Laboratory use.

8.2.4.6 Second Sample VQR Tape Request

After analysis of the tapes 1/16/76 #1 and 1/16/76 #2, it was requested that a VQR tape be made from APL #12-75 (FR-950 tape). The following is the request submitted:

> The FR-950 tape recording to be used as an input for all VQR recordings is APL #12-75.
>
> Constant settings on the VQR machine for all recordings should be as follows:
>
> Sampling interval = 1/128 nmi
> Character packing density = 5 six-bit characters per word
> Number of words per sweep = 205

The preceding parameters will establish a sampling window 8 nmi by 12.9° (147 ACP) assuming that 62000_8 words are available for storage in the IOP along with a PRF of 360 and a scan rate of 9.6 sec. for the Elwood ARSR. The window placement in the following requests assumed a window of this size.

Eight specific requests are listed in Table 8.6. The column labeled IDENT lists an internal Laboratory identification number. The start azimuth and range define the lower left-hand corner of the quantizing window. Start and stop times refer to times on the FR-950 recording and set up a time window ± 100 seconds around the time of interest. Such a large window was established because of the uncertainty in correlation between FR-1800 time and FR-950 time. In some cases the requested time window may extend before the beginning or after the end of the FR-950 tape. Obviously in these cases the requested time interval was adjusted to coincide with the limits of the FR-950 tape.

All VQR recordings were placed on two magnetic tapes, separated by end of file marks (EOF).

TABLE 8.6

IDENT	Start Azimuth (ACP)	Start Range (nmi)	Start Time (hr:min:sec)	Stop Time (hr:min:sec)	Window
2/9/76	3591	156	14:33:46	14:37:06	A
2/10/76 #1	2136	41	14:35:48	14:39:08	B
2/6/76 #2	3023	93	14:35:12	14:38:32	C
2/6/76 #3	3010	98	14:35:12	14:38:32	D
2/6/76 #1	2836	126	14:35:12	14:38:32	E
2/11/76 #1	2214	60	14:35:10	14:38:30	F
1/28/76 #C	447	99	14:33:20	14:36:40	G
1/28/76 #B	167	54	14:33:20	14:36:40	H

Two VQR tapes were received on February 24, 1976 as a function of this request. The tapes have been labeled VQR 2/24/76 #1 and VQR 2/24/76 #2.

For each window recorded, to achieve the requested range, a hardware range offset was preset before recording began. The actual range of a window as recorded on a VQR tape is the sum of this hardware offset and the recorded range of the window on the tape. Table 8.7 lists the tapes received, the windows on each tape in the order that they occur, and the hardware offset used in each case.

The actual window quantized in each case was not the desired region of the video tape. In the case of window G, a reply occurring at 101 nmi and 480 ACP's according to the VQR, data actually occurs at 101 nmi and 353 ACP's according to the Auxiliary Interpreter (AI) Mode 2 reply data. This means the VQR machine is actually quantizing a window 127 ACP's prior to the desired window. In the case of window E, a region 51 ACP's prior to the desired window was quantized.

TABLE 8.7

CONTENTS OF VQR TAPE 2/24/76 #1 AND #2

WINDOW	VQR TAPE	RANGE OFFSET nmi
A	VQR 2/24/76 #1	128
B		128
C		64
D		64
F	VQR 2/24/76 #2	32
G		96
H		32
E		96

8.2.4.7 Summary of Data Problems and Conclusions

The data problems encountered occurred primarily with the reply and VQR data. The Mode 2 tapes of beacon replies recorded at NAFEC frequently had numerous parity errors on them. This problem was found by NAFEC to be caused by RF interference from the search radar and beacon interrogation. To avoid the problem so that good Mode 2 could be obtained, a procedure was adopted where all reply tapes would be made from FR-950 recordings so that the RF equipment could be turned off. It was discovered during the analysis of target reports, however, that some target report results obtained from the CD using real time video were not the same as the results obtained when an FR-950 analog recording of the same video was used. Since the video inputted to the CD in real time cannot be quantized by the VQR machine except by the use of an FR-950 tape, this means that the only level at which the FR-950 real time difference can be observed is at the target report level. It is recommended therefore, that the RF interference problem be corrected so that Mode 2 reply data can be made from the CD using real time video. It is further recommended that the FR-950 real time problem be understood so that the impact on future investigations can be intelligently assessed.

Problems with the placement of the VQR window were also present. The regions being quantized by NAFEC were consistently different in azimuth from those requested by the Laboratory. This is not a case of negligence or

poor workmanship by NAFEC but rather comes about because of some process in the creation of the VQR tapes which has not been mutually understood by personnel (both APL and NAFEC) involved in making the tapes. It is possible, for example, that the azimuth start given to the VQR machine is interpreted by the machine as being measured from the occurrence of the azimuth reference pulse (ARP). In the Elwood CD, when the ARP occurs, a preset azimuth of -127 ACP's is loaded into the azimuth counter. If the VQR machine interprets the ARP as occurring at 0 ACP's, then it will always quantize a window 127 ACP's prior to the requested window. In one case this is exactly what happened. The problem however, is unresolved at the present time. It will be necessary to solve this problem before useful VQR data can be obtained.

8.3 APL DATA REDUCTION

8.3.1 Introduction

The analysis approach used for the beacon performance analysis relies heavily on the use of digitally recorded data. Consequently, the data reduction and analyses were done using the Laboratory computer system. Systems for displaying report, reply and VQR data on a color CRT were developed for use in the analysis. In addition other software and algorithms were written to accumulate statistical data from the target report information. A Target Report Ambiguity Analysis Package (TRAAP) was designed to detect the occurrence of target report ambiguities* and accumulate statistical information on them. A Radar-Beacon Misalignment Analysis Program (MISAL) was developed and used to detect the failure of the CD to correlate a radar report with corresponding beacon reports from the same target (presumably caused by a misalignment in range or azimuth between the radar and beacon) and accumulate statistical information on the misalignments. Finally, a Target Report Quality Analysis (TRQA) program to collect statistical information from tracked target report data was used (see Section 7.2). The following paragraphs in this subsection describe in more detail the Laboratory computer facility , the display systems, and the other analysis program that were developed.

8.3.2 Laboratory Computer Facility

Figure 8.8 is a block diagram of the Laboratory computer facility in the configuration used for the beacon performance analysis and shows all the relevant components. The computer is a UNIVAC 1230 computer designed for real time processing of data. The analyst can function interactively with the computer through the use of the color TV console. Figure 8.9 shows the console in more detail. Figure 8.10 is a color calibration chart. Color photographs of the selected console displays appear throughout Section 8. The three colors which may be projected on the display are red, green, and blue. Because the color photographs at the display do not accurately represent the colors seen on the display, the color calibration chart is included. In all discussions of color in Section 8, the display colors are used. Refer to Figure 8.10 to determine the corresponding color reproduced by the photographic process. The console keyboard is used by the operator to input necessary parameters to the analysis programs and to control and direct computer functions. Information from the computer is displayed to the operator via the data disc. The computer writes the information on the data disc, which then drives the four small screen CRT's and one 12 inch color CRT on the console. The small screen displays are used for presenting alphanumeric data while the color CRT is used to present data pictorially (such as the display of target reports in PPI fashion). The data disc maintains the display without continuous computer input, so that the computer is free to do other things without loss of the display.

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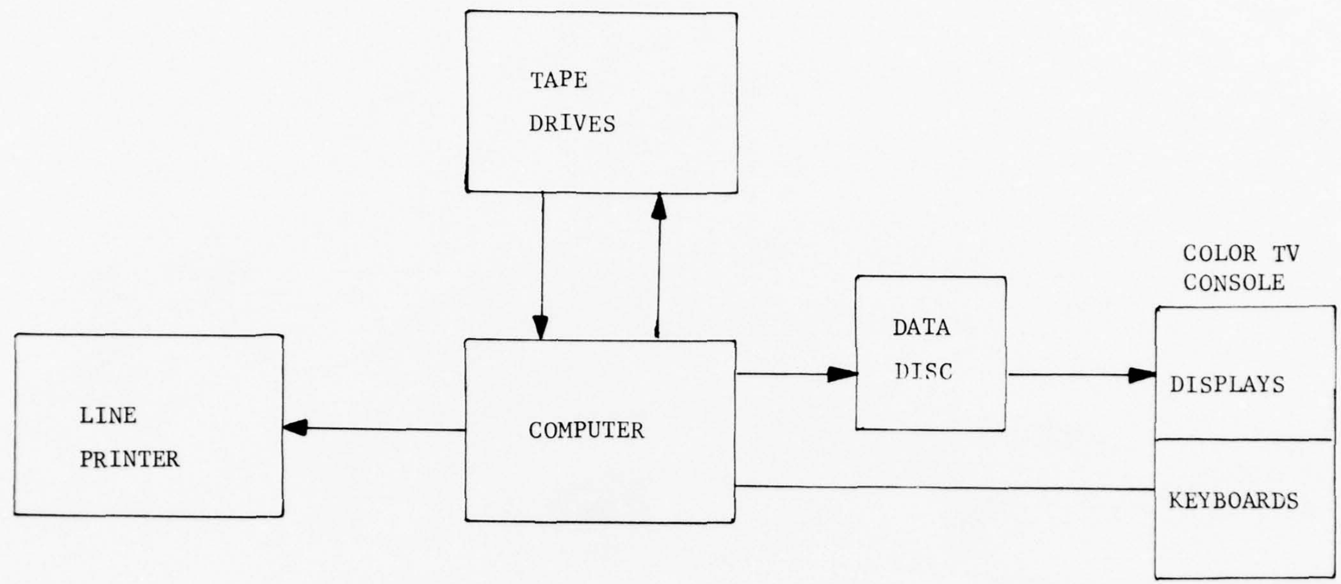
* An ambiguity is the occurrence of two or more target reports out of the CD in the same scan resulting from a single aircraft.

FIGURE 8.8

LABORATORY COMPUTER FACILITY



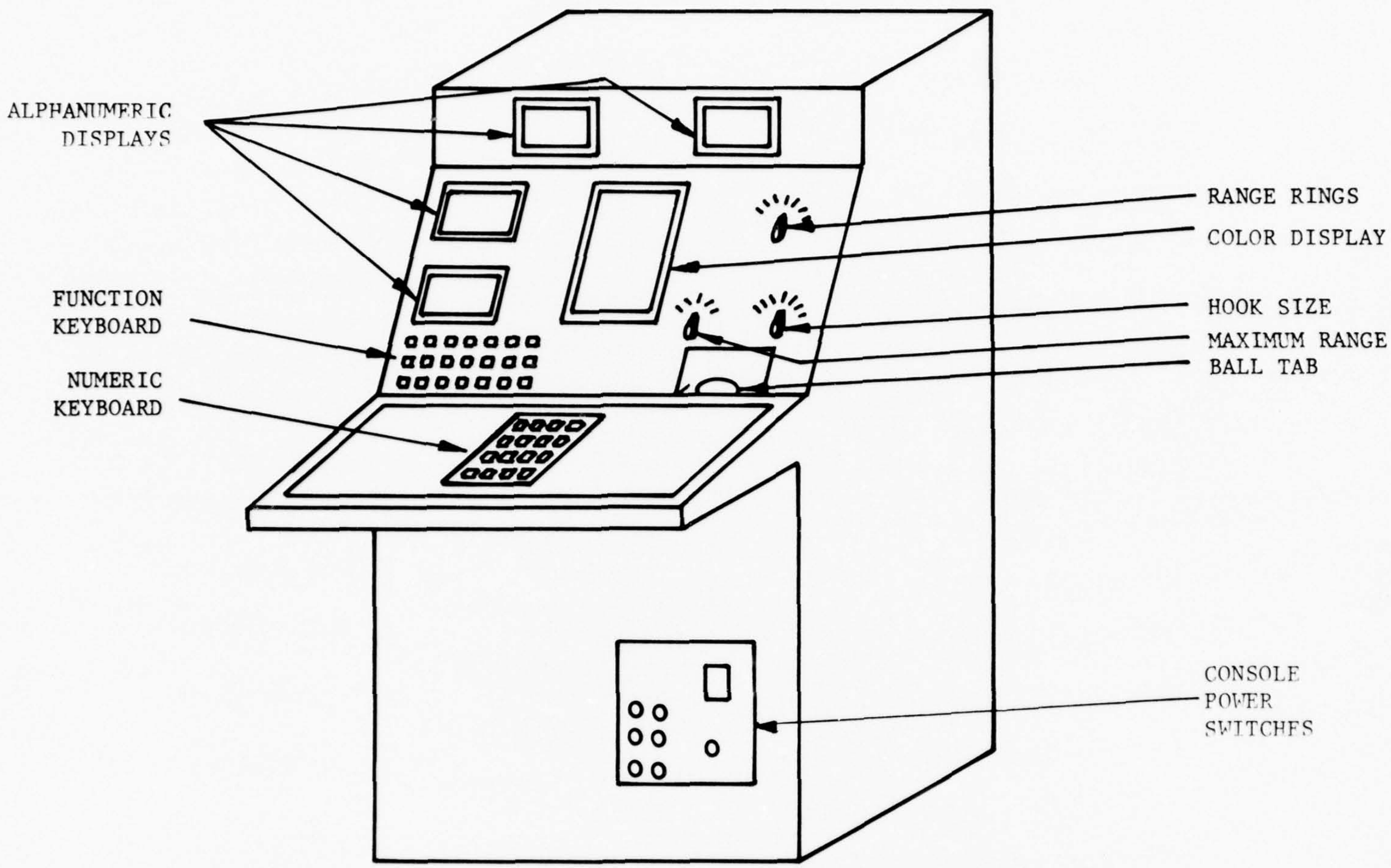
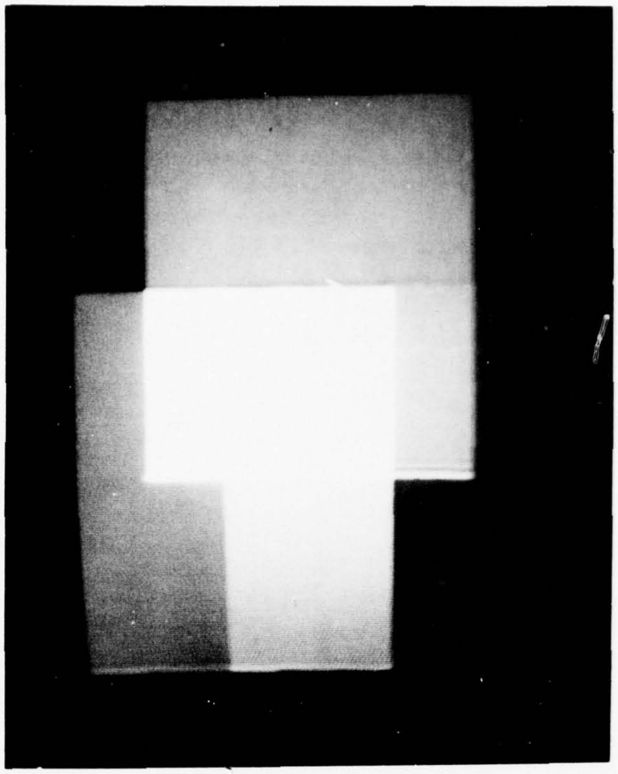


FIGURE 8.9

COLOR TV CONSOLE



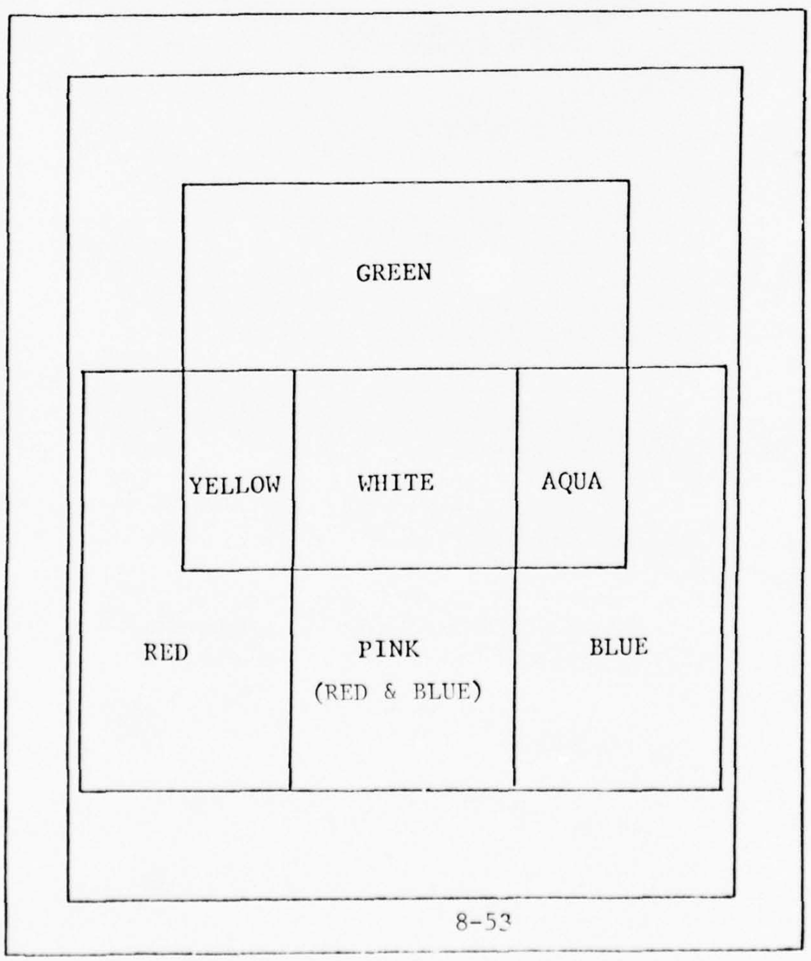


FIGURE 8.10

COLOR CALIBRATION
CHART FOR COLOR
CONSOLE DISPLAY

The line printer is used for listing data, statistics, certain system messages, and certain parameters. The tape drives are used to read recorded data and program modules into the computer. Most of the data received from NAFEC was recorded on 9 track tapes. These were converted to 7 track tapes for compatibility with the Laboratory computer tape drives which are 7 track drives. In addition, anything to be listed on the line printer can alternately be outputted to magnetic tape and then listed by the printer from the tape at a later time.

8.3.3 Display Systems

Systems for displaying CD record data, Mode 2 tape data, and VQR tape data were developed for use in the Laboratory computer facility. These display systems are described here. As the results of the study are presented the extreme usefulness of these display systems will become apparent.

8.3.3.1 CD Record Target Report Display

The CD record display system displays target reports on the 12 inch color CRT in PPI fashion. Figure 8.11 is a photograph of a typical display of beacon target reports. Approximately 20 scans of reports are shown. The range rings (in blue) have an interval of 75 nmi. Normal beacon reports are being displayed in green while target reports forming ambiguities (which are detected by the TRAAP algorithm described in 8.3.4) are displayed in red. The overlapping of red and green should produce yellow, but due to the saturation effects of the photographic process, white appears where the red and green colors overlap (see Figure 8.10). Since the data disc maintains the display, several scans of data may be read into the computer and displayed simultaneously on the screen. As the successive scans are displayed, the aircraft flight paths become apparent to the viewer and appear to form actual tracks*. Such tracks can be seen on Figure 8.11. Use of the display allows large numbers of target reports to be analyzed very rapidly. The display system has numerous capabilities. Some of the more important ones are discussed here.

Any position on the display may be offset to the center of the display. In addition, the display scale can be varied so that a particular region of interest can be "blown up" to present more detail. This is a very powerful feature, as the analyst can select an area containing interesting target reports, move it to the center of the screen, and then blow it for very detailed examination of the region.

A ball tab controlled indicator, displayed on the screen, may be used to "hook" a target report of interest. The target report data (range, azimuth, altitude, and beacon code) corresponding to the hooked target will then be displayed on one of the small screens. This feature is particularly useful for determining characteristics associated with particular observed

*The tracking function is performed by the viewer.

FIGURE 8.11 TARGET REPORT DISPLAY

CD-Record Tape	: Run 04A
Time	: 14:34:00 → 14:37:00
Number of Scans	: ~20
Range Ring Interval	: 75 nmi
Special Flagging	: Target report ambiguities are displayed in red.

anomalous target reports that might be used to characterize the anomalies and even implemented in an algorithm to detect and possibly eliminate the anomalies.

Target reports may be displayed on the screen in any of three colors and five symbols. The use of different colors and symbols permits target reports of interest to be distinguished from other target reports. For example, if a target report with a specific beacon code must be studied, the report with that code can be displayed in red while all others are displayed in green. Many of the features in the display program are algorithms that detect certain characteristics of the target reports (such as the beacon code) and then cause the reports having those characteristics to be displayed in a distinguishing color and/or symbol. Two of the more important algorithms, TRAAP and MISAL, which detect target report ambiguities and radar beacon misalignment are included in the display program. Target reports which are ambiguous may be detected and radar-beacon misalignment pair may be indicated. These two algorithms were used to produce statistical results also, and are described in more detail in Section 8.3.4. The target report display system was used extensively for the analysis of beacon performance.

8.3.3.2 Reply Display

A display system, very similar to the one designed for the display of target reports, was created to present beacon replies and target reports as recorded on AI Mode 2 tapes. Figure 8.12 is a typical display of Modd 2 tape data. Mode 3/A replies are displayed in red, Mode C in blue, and target reports in green. The range rings interval is 75 nmi. Only one scan of data is presented in this display. The target replies and target reports are both displayed in PPI fashion. Target reports and replies can be distinguished with colors or symbols. In addition, the mode of each reply may be indicated with a designated symbol or color. The display can be offset and blown up just as it can with the target report display.

The reply display system also has a ball tab positioned hook, which can be used to hook a target report or beacon reply of interest and present the associated information alphanumerically on the small screens. The hook capability was expanded for this display however. Once a target report and associated replies of interest have been identified, that region of the screen is offset and expanded. Normally, twenty or so replies will be associated with the report. A box may be positioned around all the replies associated with the report thereby "hooking" all the replies. The reply data for all the replies in the box will then be listed in azimuth order on the line printer. This allows the analyst to rapidly document a target report of interest and its corresponding replies.

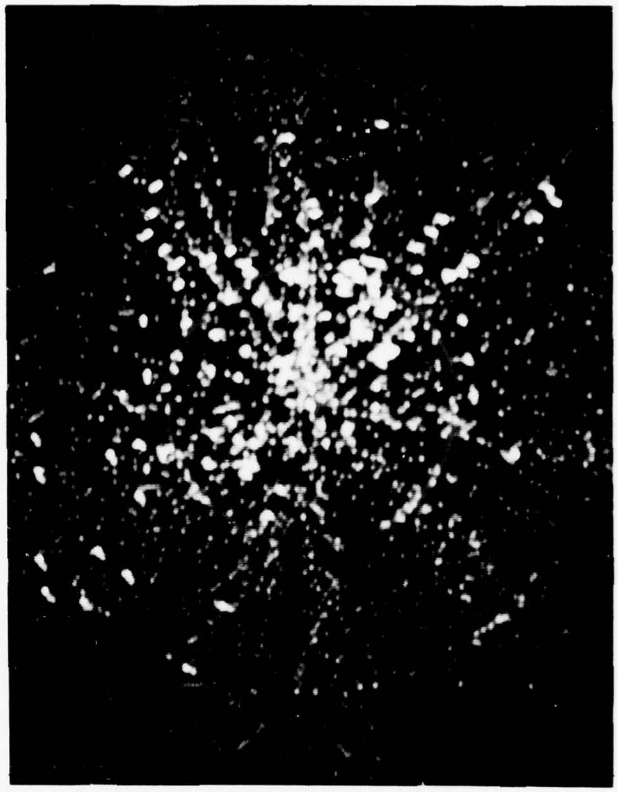


FIGURE 8.12 ONE SCAN OF AI MODE 2 DATA

Color Code:

Red - Mode 3/A Replies

Blue - Mode C Replies

Green - Target Reports

Range Ring Interval: 75 nmi

A number of anomalous reports and replies were discovered and documented using the reply display system. The results are presented in Section 8.5.

8.3.3.3 VQR Display

The VQR display system reads the digitized beacon video from the VQR tape and displays the video intensity as a function of range and azimuth on the color CRT. A display of typical VQR data is shown by Figure 8.13. The origin of the display graph is the upper left corner of the display where the range (RNG) and bearing (BRG) axis are indicated. The VQR tape number, given at the bottom of the display, was arbitrarily inserted. The display was actually made from scan 16 of window H on VQR 2/24/76 #2 (see Table 8.7). The start range and stop range, relative to the hardware inserted offset, are given on the display. For example, the hardware offset for this window is 32 nmi, so that the range of the upper right hand corner of the display is 27.3 + 32 or 59.3 nmi. The stop range is also given, but is not correct on the display due to a software problem which was later corrected. The start and stop azimuth are also given. The video intensity is indicated by color. Four thresholds can be specified interactively by the operator for the display and a color will be associated with each threshold. To the left of the graph, the four thresholds are listed, each in the associated color. The intensity of each video sample is indicated by displaying that sample in the color associated with the highest threshold that is exceeded by the video sample. In the figure, the thresholds and colors are blue-10, red-20, green-30, white (red, green and blue)-40.

A smaller segment of the display may be selected and expanded for a more detailed examination of a particular range azimuth region.

The VQR display can also display the data in another format. This is done by selecting a given azimuth on the original display. The video intensity along this azimuth will then be plotted as a function of range on one of the small screen displays. Similarly, a range may be chosen and the intensity of the video as a function of azimuth will be plotted. The graph of intensity as a function of range is particularly useful because it presents a picture of the actual beacon reply pulses. For the display of Figure 8.13, an azimuth containing a Mode 3/A reply was selected and plotted and also one with a Mode C reply. The resulting plots are shown in Figures 8.14a and 8.14b. Thus, the pulse width, shape, and amplitude may be carefully studied.

This display was used to examine the received VQR tapes. Although the requested windows of interest were not received, some of the windows did contain some beacon reply video. Because the replies occurring in the VQR windows were not the selected replies, they are not necessarily representative of any anomalies. Nonetheless, the display system was used to document the replies and extract some very useful information concerning beacon video characteristics.

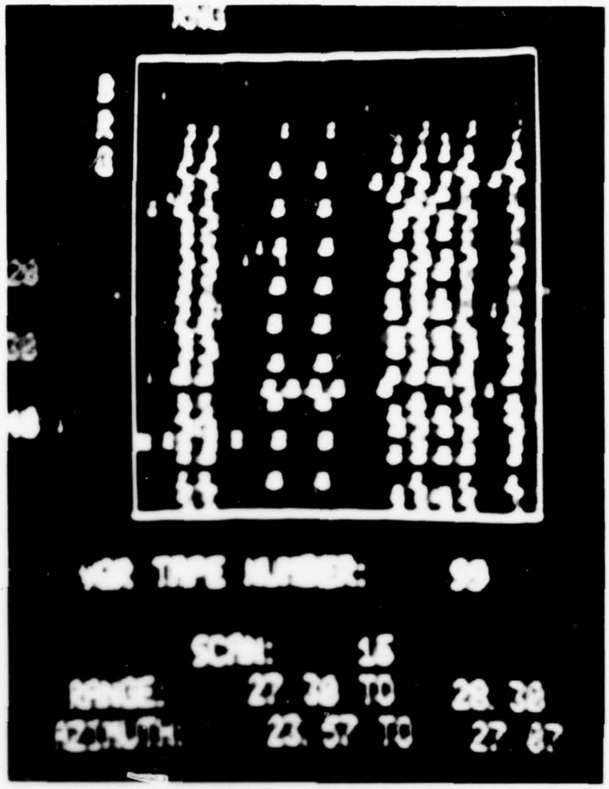


FIGURE 8.13 VQR DATA DISPLAY

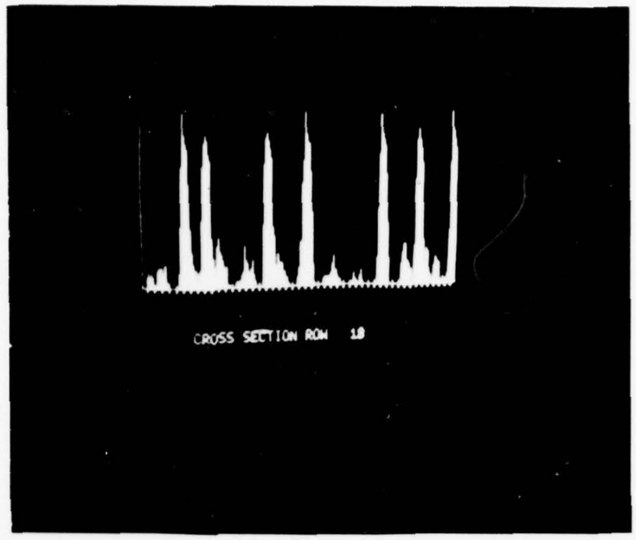
Tape : VQR 2/24/76 #2

Window : H

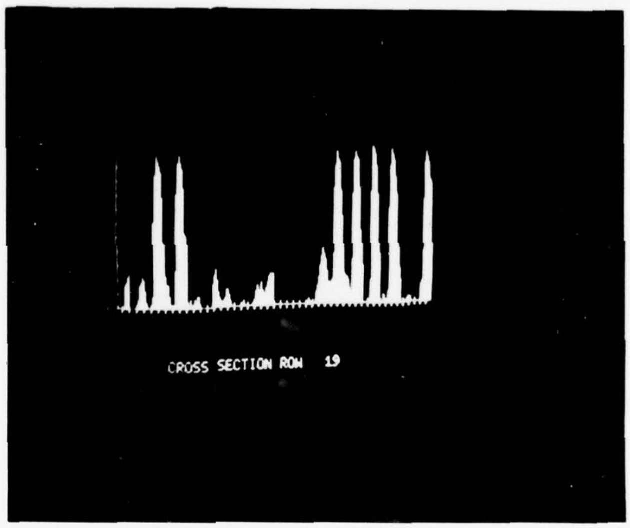
Scan : 16

Range Offset: 32 nmi

Special Note: Range stop is given incorrectly.



a. Mode 3/A Reply



b. Mode C Reply

FIGURE 8.14 PLOTS OF VIDEO AMPLITUDE VS. RANGE

Tape : VQR 2/24/76 #2

Window : H

Scan : 16

Vertical Axis : Amplitude - 5 per tic

Horizontal Axis: Range - 5 samples ($\frac{1}{128}$ nmi per sample) per

8.3.4 Software Package

Three major software programs were developed for the statistical quantification of beacon target report anomalies. The Target Report Ambiguity Analysis Package (TRAAP) was developed to detect target report ambiguities and accumulate statistical data concerning the characteristics of the ambiguities. The Radar-Beacon Misalignment Detection (MISAL) Program detects the failure of the CD to correlate radar reports with the corresponding beacon reports and accumulate statistical data characterizing the misalignment problem. The Target Report Quality Analysis Program (TRQA) is used to analyze tracked target reports. (Also described in Section 7.2). Such problems as jagged tracks and incorrectly reported beacon codes can be studied using this program. These three programs are discussed in more detail below.

8.3.4.1 TRAAP

The TRAAP program was designed to detect target report ambiguities and accumulate statistical data concerning them. A target report ambiguity occurs whenever two or more target reports corresponding to a single aircraft are produced by the CD in the same scan. Some types of ambiguities, such as range splits and azimuth splits, have the target reports very close together in range and azimuth and this feature can be incorporated in an algorithm to detect them. Other types of ambiguities, such as reflection, may be very widely spaced. For these, another method, such as the occurrence of duplicate discrete codes, must be used to detect the ambiguities.

The function of TRAAP can be broken into two steps: 1) detection of ambiguities and 2) the accumulation of statistical data. Detection will be discussed first.

The purpose of the ambiguity detection algorithm was originally to detect range and azimuth splits by searching the target reports for two or more closely spaced beacon target reports occurring in the same antenna scan. This is done by searching for two or more beacon target reports which occur within a specified range and azimuth separation interval of each other. Since real aircraft do not normally fly close together, these reports are likely to be target splits. There is the possibility that some aircraft will be flying close enough to each other to be improperly called a split target. A possible solution to this is to restrict the analysis to discrete beacon code targets only. Since only one target in a control center's area should have a particular discrete code, the occurrence of duplicate discrete codes would be the same target reported more than once, or an ambiguity. On occasions, it is noted that two actual targets have been assigned the same discrete code. These duplicate code targets are generally not flying close together, however. In addition, it has been observed that some target ambiguities involve a

change in or garbling of the code reported by the CD. Thus the duplicate code technique is not perfect either. In order to detect such ambiguities as reflection, the specific range and azimuth separation interval must be made very large, so that essentially any reports with the same discrete code will be flagged as an ambiguity.

The algorithm was designed to be implemented by computer and use target report data from CD Record tapes. A table into which CD Record data blocks may be read is established. Part 1 of the search is to find a reference report. Each message is checked to see if it is a beacon report which has not been previously called an ambiguity. When a beacon report is found which has not been called an ambiguity previously the target is referred to as a reference target, and its range and azimuth are referred to as the reference range R_r and reference azimuth θ_r.

Part 2 of the search is to find beacon target reports that are within a given range and azimuth of the reference range and reference azimuth. This is accomplished by a search through the table starting at the first message after the reference message. Upon finding a target report message, this report is named a candidate. Its range and azimuth are referred to as the candidate range R_c and candidate azimuth θ_c. The azimuth separation of the candidate from reference target is first examined to see if

$$|\theta_c - \theta_r| \leq \Delta\theta_{max}$$

where $\Delta\theta_{max}$ is an adjustable input parameter. The absolute value signs are used to account for the possibility that targets are not perfectly azimuth ordered. If the candidate does not meet the maximum azimuth separation criteria, it is rejected at this point.

Once a candidate has satisfied the maximum azimuth separation criteria, it must meet several other criteria before being flagged as an ambiguity. If it is rejected during any of the following checks, the candidate search continues with the next message in the same way. The candidate is examined to see if

$$|\theta_c - \theta_r| \geq \Delta\theta_{min}$$

where $\Delta\theta_{min}$ is an input parameter. If the minimum azimuth criteria is met, the target report is checked to see if it is a beacon report. Next, the candidate is checked to see that it is not already an ambiguity split from a previous search and rejected if it is. Last, the candidate must satisfy the range separation criteria. The candidate range is checked to see if

$$|R_c - R_r| \leq \Delta R_{max} \text{ and } |R_c - R_r| \geq \Delta R_{min}$$

where ΔR_{max} and ΔR_{min} are input parameters. If the candidate meets these criteria both the candidate and the reference reports are flagged as an ambiguity. Otherwise a new candidate is searched for.

The algorithm described finds two or more beacon reports which are within the specified range and azimuth separation of each other and calls these ambiguities. As previously stated, an additional criteria may be applied if one restricts the analysis to discrete beacon codes. This shall be called the duplicate discrete code restriction method and is included in the computer implementation of the algorithm in the form of two selectable options. One may choose to restrict the analysis to duplicate codes only and/or to discrete codes only. When the analysis is restricted to discrete codes, both the reference report and the candidate report must meet the additional criteria that the report be a discrete code beacon report. When the duplicate code option is selected, the candidate report must meet the additional criteria that its code is the same as the code of the reference report. By selecting both options the analysis is restricted to duplicate discrete codes only.

The following are required as inputs to the split detection algorithm.

1. $\Delta\theta_{min}$ and $\Delta\theta_{max}$, accurate to a degree

2. ΔR_{min} and ΔR_{max}, accurate to 1/8 nmi.

3. The option for duplicate codes only may be selected.

4. The option for discrete codes only may be selected.

The ambiguity detection portion of the TRAAP program is used in conjunction with the CD Record target report display program and the Mode 2 tape target report display to detect the ambiguities in the target reports and flag them on the display in a distinguishing color or symbol. In addition, once the ambiguities are detected, the remaining portion of the TRAAP program collects statistical data on them. This portion of TRAAP, called the ambiguity statistics algorithm, is described next.

This ambiguity statistics algorithm was written in such a way that it could be used in conjunction with the ambiguity detection algorithm. Together these two routines form a package (TRAAP) that can detect beacon target ambiguities in the reports recorded on CD Record tapes and accumulate statistical data. There are input parameters to the split statistics algorithm:

1. Start time, T_S
2. End time, T_E
3. Lower Range Bound, R_{min}
4. Upper Range Bound, R_{max}, and
5. Minimum Altitude
6. Maximum Altitude

Each target report message has a time recorded in tenths of seconds that is the time of day that the message was transmitted by the CD over MODEM lines. The statistics package keys off this time, and accumulates statistics only for those reports and splits that occur in the time interval $[T_S, T_E]$. Also, only splits for which the reference target range R_r satisfies $R_{min} \leq R_r \leq R_{max}$ are processed. The minimum and maximum altitude specifies the limits of data collected for the altitude distribution plots, but does not result in reports outside of the altitude limits being rejected as potential ambiguities. The algorithm consists of three major routines:

1. Count Total Targets
2. Count Current Splits
3. Accumulate Data

These routines are called separately by the ambiguity detection algorithm as the required information for each routine becomes available. Figure 8.15 is a simplified version of the ambiguity detection algorithm with the addition of the ambiguity statistics routines. The functions performed by the ambiguity statistics routine are denoted by a shadowed box, rather than a plain box.

Recall that the ambiguity detection algorithm first finds a beacon reference report, then searches for all reports which form an ambiguity with the reference. The reports examined are called candidate reports, and if they are found to form an ambiguity with the reference report the reference and any candidates that form the ambiguity with it are called an ambiguity. The group size is the number of reports in the ambiguity. This number has no limit but is usually observed to be less than five. If a candidate is found to form an ambiguity with the reference report both it and the reference report are stored by the box labeled Count Current Splits. If other candidates are found that also form an ambiguity with the same reference these are also stored. When the ambiguity detection algorithm determines that no other candidates exist the ambiguity group is considered complete. The data for characteristics are extracted by the box labeled Accumulate Data from the report data stored by Count Current Splits. The stored report data is then dumped and new data stored is made ready for the next reference report.

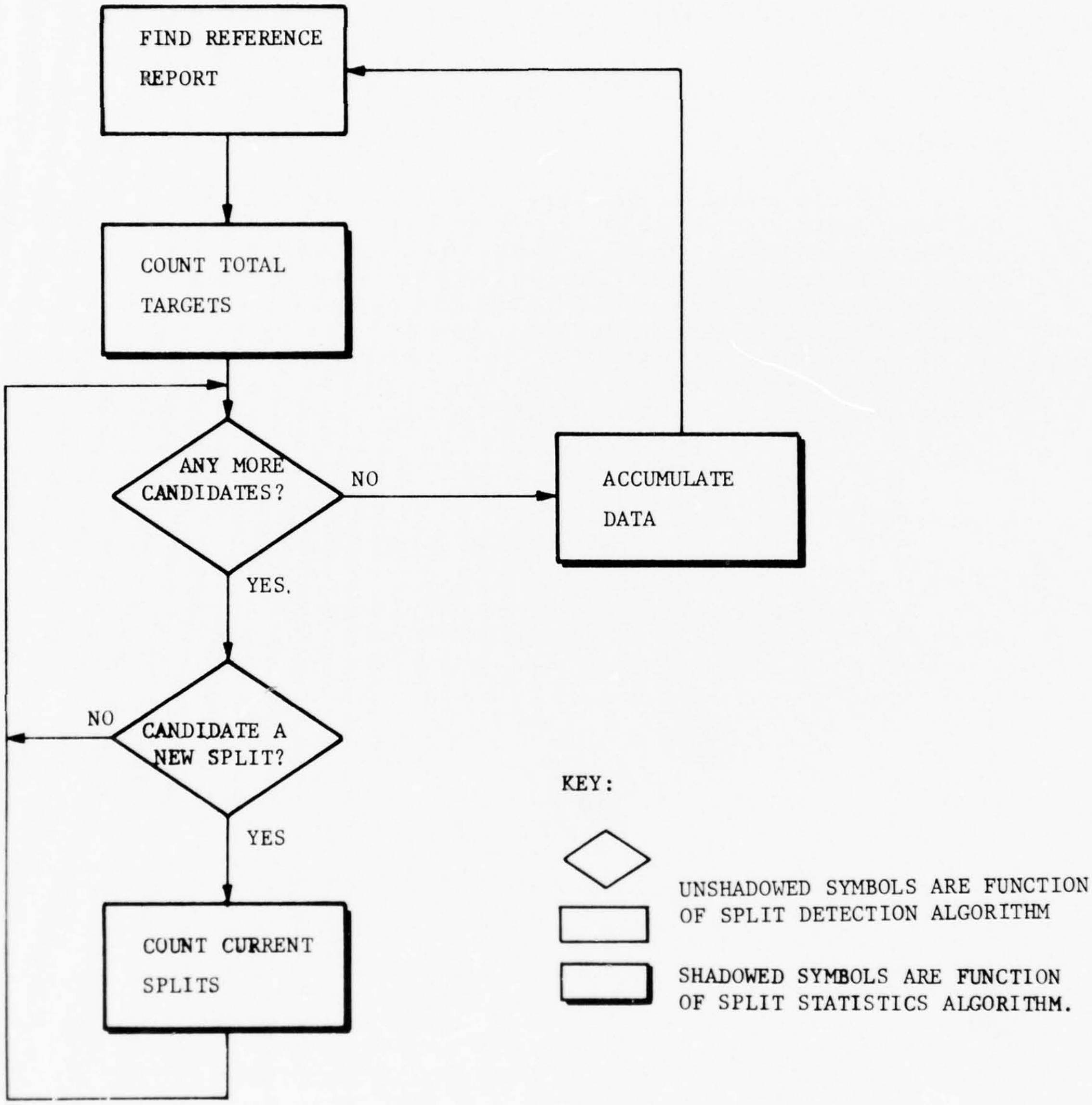


FIGURE 8.15

SIMPLIFIED SPLIT DETECTION ALGORITHM
WITH CALLS TO THE SPLIT STATISTICS PROGRAM

When all the data has been accumulated, the Count Total Targets routine calls up the output routine. The routine organizes the data, makes various computations and prints out the data. The data is presented in three forms: 1) lists, 2) tables and 3) histograms.

The split statistics package was implemented in the computer facility and used to analyze large amounts of data with very useful results.

8.3.4.2 MISAL

The Radar-Beacon Misalignment Detection Algorithm simply searches the target report data for a beacon report that is not radar reinforced. It then searches the target report data for the occurrence of a search radar target report which occurs within a specified range and azimuth window around the beacon report. If one is found, a radar-beacon misalignment is said to occur. If two or more radar reports occur in the window, the one closest in actual distance to the beacon report is chosen as the radar report that corresponds to the beacon report. Inputs to the detection algorithm specifying the window around the beacon report are the following:

1. ΔR_{min} - minimum range separation required
2. ΔR_{max} - maximum range separation allowed
3. $\Delta\theta_{max}$ - maximum azimuth separation allowed

The misalignment detection program is included in the CD Record target report display package. It is used to detect the misalignments so that they can be indicated on the display via the insertion of a special color or symbol.

In addition, a misalignment statistics program was designed for use with the detection package. Together, they form the MISAL program being discussed. Four inputs are required by the statistics package.

1. T_S - start time of the analysis
2. T_E - end time of the analysis
3. R_{max} - maximum range for acceptance of beacon reports
4. R_{min} - minimum range for acceptance of beacon reports

The primary form of presentation for the misalignment statistics is a list of collected statistics and histograms. The MISAL program was used in the Laboratory computer facility to characterize the misalignment problem.

8.3.4.3 TRQA

The TRQA program is discussed in Section 7.2.

8.4 ANALYSIS OF BEACON TARGET REPORTS

8.4.1 Introduction

This section describes the analysis of the beacon target report data as recorded on the CD-record digital magnetic computer tapes. The purpose of the analysis was to identify problems in the target report data which indicate a deficiency in the beacon processing of the CD. The first phase of the analysis of target reports was to display the target reports using the CD-record target display system described in Section 8.3. The displays produced were analyzed visually and several possible areas of difficulty in the beacon processing were identified. Additional display capabilities were added and computer programs were designed to show the problems more explicitly and indicate the frequency and severity of the problems.

The following problems were identified for further consideration at the reply and video analysis levels.

1. Target Report Ambiguities
2. Radar-Beacon Misalignment
3. Missing Reports
4. Jagged Tracks
5. Incorrect Reported Code

Figure 8.16 illustrates several scans of target report information for an aircraft. The display was offset and "blown up" to clearly illustrate the aircraft flight path. Ambiguous target reports are in red while the others are green. Some of the above mentioned problems are illustrated by this photograph.

A target report ambiguity occurs when, on a single scan, two or more reports corresponding to a single aircraft are output by the CD. Four pairs of closely spaced ambiguities are shown in Figure 8.16 in red. These additional reports result in unnecessary information being transmitted across the modem lines and create an additional burden on the 9020 computer system at the ARTCC. Further, the display of these ambiguous reports to the controller creates an additional problem for him, thus reducing his capacity for carrying out his primary purpose of directing air traffic. The existence of ambiguous target reports will also result in problems to future automation of NAS. One of the proposed capabilities to be added for additional automation of the system is that of automatic detection of aircraft which are on a potential collision course. Should an aircraft result in an ambiguity where two very closely spaced reports are generated,

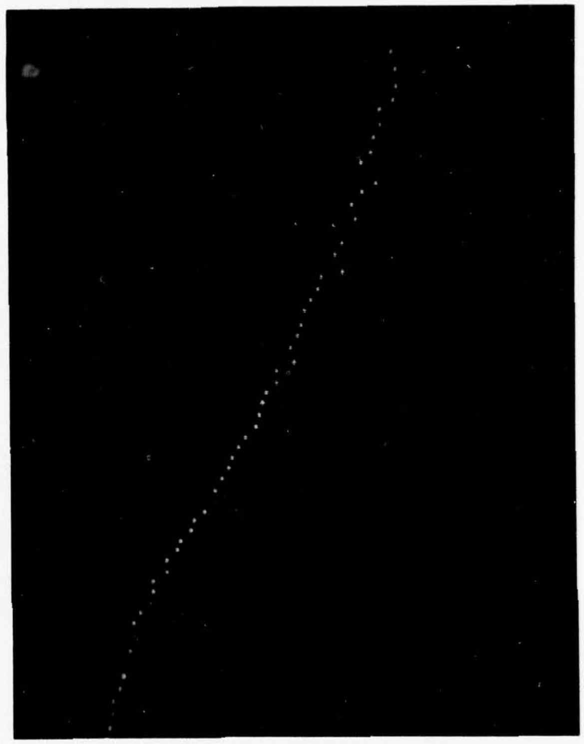


FIGURE 8.16

BEACON TARGET REPORTS

such as a range split, the collision detection software might falsely signal that a collision was imminent. Target ambiguities, since they add to the system load, affect controller efficiency, and potentially affect future automation plans, are considered a problem serious enough to merit further investigation. Software to detect, characterize, and classify ambiguities was developed and used to quantify the target ambiguity problem. The software package, called the Target Report Ambiguity Analysis Package (TRAAP), was designed to 1) detect ambiguities so that they can be distinguished by the use of color and/or symbols on the display and 2) extract target report statistics and statistics characterizing the frequency and nature of the ambiguities. The software package is described in more detail in Section 8.3. The results are presented in the form of photographs, tables and plots.

Radar-beacon misalignment refers to the failure of the CD to correlate a beacon report with its corresponding radar report. When functioning as designed, the CD will recognize that incoming radar hits correspond to incoming beacon replies from the same target and will produce a single beacon report that is flagged as being radar reinforced. When the CD fails to do this, two reports, a radar report and a beacon report, will be transmitted to the ARTCC. While it appears that controllers are not overly concerned about the display of this extra report, its existence on the display must still be given consideration by the controller, at least to the extent that he observes it and decides to ignore it. As controller workloads are often extremely heavy, it would be best to eliminate the display of all unnecessary reports. The extra radar report also placed an extra burden on the modem lines and the 9020 computer system. It was therefore considered worthwhile to include this problem for additional study. A program to detect and quantify the radar-beacon misalignments was designed. Basically, the program searches a small window around each non-radar-reinforced beacon report for the occurrences of a radar report. If one is found, the pair is flagged as a radar-beacon misalignment and the range and azimuth displacement of the radar report from the beacon report are extracted for use in histograms. The results of the analysis of this problem are presented and discussed.

The next problem is missing reports. When the target report data for several scans is displayed simultaneously, aircraft flight paths become apparent. By visual inspection, it can be seen that aircraft tracks exist. In Figure 8.16, it can be clearly seen that the successive scans of report data are forming an aircraft track. Ideally, on each scan, a beacon report will occur for each existing track. Sometimes, however, a report will not occur on the track, though one did occur on a previous scan and subsequent scans. Such an event is called a missing report. A missing report is pointed out in Figure 8.16. The target report data being displayed to the controller is tracked by the 9020 system before

being displayed. A missing report into the 9020 system, occurring on a track already established by the 9020 tracker, will result in a report being displayed to the controller which is developed by use of predicted position based on past information. This, of course, has a direct affect on track accuracy. The frequency of occurrence of missing reports is measured by use of blip-scan, the ratio of hits on a track to the number of scans for which the track existed. In order to develop this quantity, tracked target report data must be used. A program, called the Target Report Quality Analysis package described in Section 7.2, was developed to analyze tracked target report data and extract blip-scan. The tracked target report data was produced using an APL developed tracker. The TRQA program was developed to complete the analysis of Section 7.2. This program was applied only on a very limited basis before the termination of work on the en route contract and the results are presented.

Jagged tracks refer to the occurrence of tracks for which a smooth flight path cannot be drawn through the reports on the track. The track of Figure 8.16 appears to be a jagged track. It is assumed that the aircraft which generated the target reports in Figure 8.16 prescribed a smooth flight path in the air. If a smooth line were drawn on Figure 8.16 to approximate the aircraft flight path, it would be evident that the target reports were deviating from the line. As en route aircraft are not likely to follow a path such as that indicated by the target reports, it is assumed that a centroiding problem or ranging problem has resulted in the pattern of target reports illustrated. Such tracks were frequently observed using the display program. Improper centroiding and ranging can present significant problems to the system at the ARTCC. For one thing, trackers normally assume a smooth flight path, and look for a target report to occur at a position predicted on the basis of a smooth prediction using past track parameters. When a target report does not occur at its predicted position, the tracker must either coast (produce a predicted report), or go through some additional logic to find the misplaced report. In either case, tracker load is increased. Furthermore, the accuracy with which the target position is known is reduced because of the incorrect determination of target report position. The CD output analysis program contains logic to measure track smoothness and presents statistical results of this. The program was applied on a limited basis.

An incorrectly reported code occurs when a target report on a track has a code that is different from those reports occurring prior to or subsequent to it on the same track. As the frequency of occurrence of incorrectly reported codes cannot be easily determined from the display of target reports, algorithms to extract code change data from tracked target reports are included in the TRQA package which was applied on a limited basis. Beacon code is used by the controller to identify aircraft which he is controlling and also by the tracker in the 9020, so the occurrence of incorrectly reported codes is potentially a problem and will become more so with increased automation.

Section 8.4.2 through 8.4.5 present the results of the analysis of target reports. Section 8.4.2 presents the beacon target report characteristics. The information presented in this section characterizes the target report data in general. Statistical data presented in the section, such as the distribution of target reports in range, azimuth, and altitude was derived during the analysis of ambiguities by the TRAAP program.

It was discovered during the analysis of target reports that the report data collected using real time beacon video was not the same as report data generated from an FR-950 analog recording of the same video. Photographs of target report data to illustrate this problem are presented in Section 8.4.2.

As indicated by Section 8.2, two trips were made by APL personnel to the Elwood facility for data collection. On the first trip, some FR-950 tapes for further study were selected, and used to produce CD records. On the second trip, some of these same FR-950s were used to produce another set of CD records. It was discovered during analysis of the second set of CD records that results obtained were not necessarily the same even though the same FR-950 video was used to make the CD record. Also, as noted in Section 8.2, during the second data collection run, beacon processing was apparently blanked above and below certain ranges, so that while the first set of data collected from the FR-950s covered the full 256 nmi, the second set of data collected covered a smaller area. To do a proper comparison on the first set of data with the second set, it was necessary to limit the analysis to ranges for which beacon data was processed during both collections. For example, consider an FR-950 which is played through the CD once with the full 256 nmi of video processed. Then the FR-950 is played through again, this time only the video between 10 nmi and 188 nmi is processed. Only the results obtained by analyzing both tapes between 10 nmi and 188 nmi are comparable. In the data presented, it will be noticed that the range limits of the analysis performed was frequently restricted. Furthermore, the analysis start and stop times are adjusted so that only CD-Record data covering exactly the same segment of the FR-950 tape is compared.

Section 8.4.3 discussed the analysis of the target report ambiguities. Target report ambiguities are broken into five classes based upon the range and azimuth separations of the ambiguities. The collected CD record tapes were then analyzed, using the TRAAP program, and the number of ambiguities fitting into each category were determined for the data. Distributions of the ambiguities in range, azimuth and altitude are shown, as well as the distribution of the range and azimuth separation of target reports forming the ambiguities. It was discovered that the difference in the target report data caused by use of the FR-950 video as opposed to real time video also affects the ambiguity rate. This phenomena is discussed in 8.4.3 also.

Section 8.4.4 addresses the analysis of radar-beacon misalignments. The MISAL program was used to extract the misalignment rates from the target report data. The range separation distribution and azimuth separation distribution of the beacon and associated radar report are given. In cases where an offset was known to exist, the misalignment rates are naturally large. However, the radar reinforcement rate which would exist with proper alignment can be estimated from the collected data.

Section 7.2 discusses the characteristics of jagged track, missing reports (blip-scan) and beacon code changes. All of this data was extracted by the TRQA program which uses tracked target report data. The TRQA program was completed only recently and was applied on a limited amount of data. Nonetheless, some interesting information was produced, and is presented in this section.

8.4.2 Target Report Characteristics

This section presents data which characterize the nature of beacon target reports. Most of the data presented herein was collected during the analysis of beacon target report ambiguities using the TRAAP program. While it was not the expressed purpose of the analysis of target report ambiguities to collect this data, it was necessary to do it as part of the study of the ambiguity problem. For example, in the analysis of target report ambiguities, the distribution of the ambiguities in range, azimuth and altitude are studied. Such information is not useful, though, unless the corresponding distributions of target reports are also known. Although the distributions and other statistical information collected are used primarily for the analysis of beacon processing problems, they are also interesting in their own right and therefore this section, presenting the target report characteristics, is included. Photographs illustrating the difference between beacon target report data obtained using real time beacon video and that obtained using FR-950 beacon video (made from the corresponding real time video) are included. Because of the fact that the analysis that produced this data was done to study the ambiguity problem, the input parameters to the TRAAP program were adjusted for this purpose. Consequently, the settings are not always ideal for characterization of target reports. The impact of this will be noted as necessary during the following discussion.

During the data collection at Elwood, certain steps were taken to demonstrate the quality and reliability of the FR-950 analog recording process. For example, on the first Laboratory trip to NAFEC, real time radar and beacon video were played through the CD to produce a CD-Record tape called RUN 04A. An FR-950 recording was made of the real time video and then played back through the CD two more times to produce CD-Records RUN 04B and RUN 04C. Comparison of tape RUN 04A (real time) with either RUN 04B (FR-950) or RUN 04C (FR-950) can be done to see how well the results obtained using FR-950 video match the results obtained with the corresponding real time video. Comparison of RUN 04B with RUN 04C is done to check the repeatability of results obtained using an FR-950 tape. Similarly, on the second APL trip to NAFEC, CD-Records were made using the same FR-950's selected on the first APL trip. Comparison of CD-Records made on the first trip with CD-Records made on the second trip from the same video was done to determine the repeatability of results obtained with an FR-950 tape after a longer time. Table 8.8 lists, in groups, the CD-Record tapes that cen be compared. The distinguishing feature (i.e., video source and first or second trip) are indicated by Table 8.8.

TABLE 8.8

CD-Record Tapes That Can Be Compared

1. RUN 001 (FR-950, first trip), CDR-804 (FR-950, second trip)

*2. RUN 002 (FR-950, first trip), CDR-805 (FR-950, second trip)

3. RUN 04A (real time, first trip), RUN 04B (FR-950, first trip), RUN 04C (FR-950, first trip), CDR-807 (FR-950, second trip)

4. RUN 005 (FR-950, first trip), CDR-803 (FR-950, second trip)

5. CDR-809 (real time, second trip), CDR-812 (FR-950 second trip)

In order to do a proper comparison of these tapes, the analysis must be performed over segments of the tapes which were made from exactly the same video so that the corresponding times on CD-Record tapes must be determined. In addition, although it was not requested by APL, apparently the beacon processing was blanked above and below some range on the second APL trip. Blanking was not used on the data taken during the first APL trip, so that some target reports occurring on the CD-Records made from the first APL trip are not on the tapes made from the second APL trip. To properly compare the tapes then, the analysis must also be performed over regions for which neither tape is blanked. Table 8.9 lists all the CD-Records used and the corresponding start and stop times and minimum and maximum ranges over which the analyses must be done for comparison of the CD-Record tapes.

Note in Table 8.8 that RUN 002 and CDR-805 can be compared. These two CD-Records were supposed to have been made from the same FR-950 tape (Elwood #8, 1/30/74). However, both tapes were displayed and it was determined that the target report data was entirely different. The problem was investigated further by having the FR-1800 tapes used to make each CD-Record located and used to make two more CD-Records. These were compared and found to be different also, eliminating the possibility that the wrong FR-1800 was used and indicating that either the wrong FR-950 tape was used the second time, or that the FR-950 tape used was rerecorded but not relabeled. In any event, the actual FR-950 used to make CDR-805 is not known. Although a conclusion based on data from CDR-805 cannot be made since it was made under unknown conditions, the data from it is presented anyway.

* It was later discovered that CDR-805 was not made from the FR-950 used to make RUN 002, so these two cannot, in fact, be compared.

TABLE 8.9

Analysis Limits for Comparison of Data

Tape	Times Start - Stop	Range (nmi) Min	Max
RUN 001	9:51:01 - 10:11:00	11	188
RUN 002	10:58:01 - 11:16:01	0	256
RUN 003	13:08:00 - 13:28:00	0	256
RUN 04A	13:34:00 - 14:47:21	11	188
RUN 04B	15:18:56 - 15:32:17	11	188
RUN 04C	15:42:39 - 15:56:00	11	188
RUN 005	10:12:24 - 10:26:24	11	245
RUN 006	11:18:00 - 11:39:00	0	256
CDR-803	13:34:39 - 13:48:39	11	245
CDR-804	14:33:21 - 14:53:21	11	188
CDR-805	15:06:57 - 15:24:57	0	256
CDR-807	9:41:21 - 9:54:42	11	188
CDR-809	10:54:00 - 11:14:00	11	210
CDR-810	11:23:00 - 11:43:00	11	210
CDR-811	13:00:00 - 13:15:00	11	210
CDR-812	13:30:50 - 13:50:50	11	210

The statistics collected allow a determination of the average number of beacon reports per scan, and permit a breakdown into reports with discrete and non-discrete beacon codes. Table 8.10 tabulates this information. The analysis times and ranges were not adjusted for comparison of corresponding CD-Record in this table. Tapes for which the information was available are listed, along with the start and stop times of the analysis, scan rate of the beacon antenna, total scans analyzed, total number of beacon targets, average number of targets per scan, total discrete beacons average number of discrete beacon code targets per scan, and the percent of discrete and non-discrete beacon codes that occurred. The average number of beacon target reports per scan varied between about 100 and 230. All the tapes in the table with the exception of RUN 005 and RUN 006 were made using video obtained at Elwood. RUN 005 was made from Paso Robles FR-950 video and RUN 006 was made from St. Louis FR-950 video. The variability in the average number of targets per scan from tape to tape is readily seen from this table and shows how variable the aircraft traffic is from time to time at Elwood. The average number of discrete beacon codes per scan is also quite variable. The percentage of discrete beacon codes per scan varies from about 25 to 70.

Although the analysis times are not exactly aligned for an exact comparison of RUN 04A, RUN 04B and RUN 04C, they are close enough that the average data collected may be compared. Interestingly, the average number of targets per scan for RUN 04B or RUN 04C made with the FR-950 video is more than that for RUN 04A made with real time video, although the percentage of discrete and non-discrete are about the same for all three tapes (60% discrete, 40% non-discrete). The reason why the number of targets differs between the real time video results and FR-950 video results has not been determined. It is suspected, however, that the video amplitude from the receiver itself may be different from the video amplitude that results when the FR-950 tape is played back. Another parameter that could cause the difference is the bandwidth of the video signals. Making an analog recording of the video and playing it back can surely only cause the bandwidth and the signal to be reduced, thereby spreading out the beacon video pulses. It is strongly recommended that the problem be resolved so that is impact on future investigations of the system using FR-950 tapes can be accurately assessed.

In a group, the same FR-950 was used for all tapes made from an FR-950. Besides the FR-950/real time problem alluded to here, the major conclusion to be drawn from Table 8.10 is the extreme variability of the target density and target mix (discrete and non-discrete) that is observed from time to time.

TABLE 8.10 TARGET REPORT STATISTICS ANALYSIS RANGE: $0 \rightarrow 256$ nmi

Run	CD-Record Analysis Time		Scan Rate Sec/Scan	No of Scans	Total Bcn Reports	Avg Bcn Reports Per Scan	Total Discrete Bcn Reports	% Discrete Beacons	% Non-Discrete	Ave Discrete Beacons
	Start	Stop								
RUN 001	9:51:00	10:12:00	9.6	131	19675	150	13518	69	31	104
RUN 002	10:58:00	11:16:00	9.6	112.5	23601	209	9385	40	60	84
RUN 003	13:08:00	13:28:00	9.6	125	19898	159	5471	27	73	44
RUN 04A	13:34:00	14:47:21	9.6	83	16939	203	10325	61	39	124
RUN 04B	15:19:00	15:32:21	9.6	71*	16604	233	9804	59	41	138
RUN 04C	15:42:00	15:56:00	9.6	88	19353	220	11385	59	41	130
RUN 005	10:12:00	10:33:00	12	105	11904	113	2851	24	76	27
RUN 006	11:17:00	11:38:00	9.6	131	13085	100	3134	24	76	24
CDR-810	11:23:00	11:43:00	9.6	125	14295	114	9289	65	35	74
CDR-811	13:00:00	13:15:00	9.6	94	11640	124	8243	71	39	88

* VISUAL INSPECTION REVEALED THAT 12 SCANS ARE MISSING

Another set of data was analyzed using times and ranges that were aligned for comparison of corresponding CD-Record tapes. This data came from an ambiguity analysis which was being restricted to duplicate discrete code targets only. Therefore only discrete code beacon target reports were counted. Table 8.11 lists the results of the analysis for those tapes which can be compared. Four groups of CD-Records for inter-comparisons of results exist and the table is listed with each group together for convenience in comparing the results. The APL trip on which each tape was made and the video source are indicated in Table 8.8. In cases where a group has both an FR-950 source and a real time source, the FR-950 was made from the corresponding real time source. The primary column of interest in Table 8.11 is the average number of discrete beacon codes per scan. Considering first just those tapes made from FR-950's, it can be seen in groups 1, 2 and 3 that the CD-Record made on the second trip to Elwood have a lower average number of target reports per scan than corresponding CD-Records made on the first trip to Elwood. Yet when the same FR-950 was played through the CD twice in succession (both on the first trip) to make tapes RUN 04B and RUN 04C, the average number of targets per scan was the same. This tends to indicate the possibility that some parameter, such as video gain, was set differently for the two different APL trips to Elwood.

Differences between results obtained with real time video and those obtained with FR-950 video are also noted. In group 4, CDR-809 was made from real time video while CDR-812 was made from an FR-950 tape of the same video. In this case, using the FR-950 resulted in a lower average number of targets per scan than the real time video. In group 2, tapes RUN 04B and RUN 04C, which were made on the same day (first trip) as RUN 04A using an FR-950 of the real time video used to make RUN 04A, have a higher value than the RUN 04A, while the tape made on the second trip (CDR-807) has a lower value than RUN 04A.

The conclusion that can be hypothesized from all of this is that some parameter(s) relating to the use of the FR-950 video was set to a value on the first APL trip to Elwood which resulted in the FR-950 video producing more beacon targets per scan than the real time video while on the second APL trip, they were at a value which caused fewer targets per scan than real time video when FR-950 video was used. This is simply a suggested cause. As previously noted, it is recommended that the FR-950 video and real time video be thoroughly studied to determine the actual cause.

8.4.2.1 Target Report Distribution

In addition to these statistics collected, for each ambiguity analysis that was run, the distributions of target reports in range, azimuth, and altitude were plotted. One would expect that if aircraft were uniformly distributed in the airspace, a plot of the range distribution of target reports would show relatively more reports at longer ranges because a larger area of

FIGURE 8.11

CD-RECORD STATISTICS

Group	Run	Analysis Time		Analysis Range		Scan Rate Sec/Scan	No of Scans	Discrete Beacon Reports	Ave Discrete Bcn Reports Per Scan	Trip No.	Video Source
		Start	Stop	Min	Max						
1	RUN 001	9:51:00	10:11:01	11	188	9.6	125	12303	98	1	F
	CDR-804	14:33:21	14:53:21	11	188	9.6	125	10082	80	2	F
2	RUN 04A	13:34:00	14:47:21	11	188	9.6	83	10008	121	1	R
	RUN 04B	15:18:56	15:32:17	11	188	9.6	71*	9462	133	1	F
	RUN 04C	15:42:39	15:56:00	11	188	9.6	83	11003	133	1	F
	CDR-807	9:41:21	9:54:42	11	188	9.6	83	7135	86	2	F
3	RUN 005	10:12:24	10:26:24	11	245	12.0	70	2051	29	1	F
	CDR-803	13:34:39	13:48:39	11	245	12.0	70	1388	20	2	F
4	CDR-809	10:54:00	11:14:00	11	210	9.6	125	15839	127	1	R
	CDR-812	13:30:50	13:50:50	11	210	9.6	125	13174	105	2	F

* 12 SCANS LOST

1. 1 = FIRST TRIP: 2 = SECOND TRIP
2. R = REAL TIME: F = FR-950

airspace is covered at the longer ranges. In fact, target distribution in the sky is far from uniform, and several different distributions as a function of range are observed. Figure 8.17 is a plot of frequency (normalized to one) of target reports versus range for CD-Record RUN 001. At long ranges relatively fewer targets occur, while at close ranges the number of target reports becomes large, until about 40 nmi. Below 40 nmi the number of targets decrease as range decreases. The shape of this distribution is explained by the fact that nearby airport activity creates a higher density condition at short ranges and few aircraft are flying over the ocean at the longer ranges. This general shape is rather typical but other types of shapes were also observed. Figure 8.18 is the range distribution for RUN 003. Strangely no reports occurred beyond about 150 nmi. The reason for this is not known but may have been a result of weather conditions causing aircraft traffic patterns to be changed. The range distribution for RUN 005 shown in Figure 8.19 was closer to uniform in range than for the other runs although the tendency to increase with decreasing range is evident. The video for this tape was made at Paso Robles, which naturally has a different aircraft traffic situation than Elwood. Figure 8.20 is the range distribution for RUN 006, made from St. Louis video, and also has a distinctive shape. The little "bump" between 114 nmi and 178 nmi is probably a result of activity at a nearby airport. The distribution for CDR-809 is shown in Figure 8.21. This tape was made from Elwood video. Note that the shape is about the same as that of Figure 8.17, also from Elwood, except that in this case the number of targets increases with decreasing range all the way in as opposed to the distribution shown in Figure 8.17 which begins to decrease with decreasing range below 40 nmi.

Generally, it can be concluded that the range distribution will vary depending on the existing traffic conditions and that a "typical" distribution does not really exist.

Figure 8.22 is a plot of frequency versus azimuth for target reports from RUN 001. The azimuth of each bin is determined by multiplying the number given in the column labeled AZMUTH corresponding to the bin by 360°. Notice that a sector exists in which relatively few targets exist. This distribution is very typical of all the data collected. At the Elwood site, the direction where few target reports are present corresponds to the ocean. The distribution is not necessarily typical of all sites, however, even though all the collected data exhibited the shape.

Altitude distributions were developed from altitude information provided by targets equipped with Mode C transponders. Thus the altitude distributions are only for the Mode C equipped aircraft. Several different characteristic distributions were observed. Figure 8.23 is the altitude distribution of target reports from CD-Record tape RUN 001. The altitude

FIGURE 8.17 RUN 001

NORMALIZED TARGET REPORT RANGE DISTRIBUTION

RANGE(nm)	PERCNT
0.000	0.012
7.125	0.018
14.250	0.025
21.375	0.026
28.500	0.039
35.625	0.048
42.750	0.070
49.875	0.062
57.000	0.050
64.125	0.077
71.250	0.080
78.375	0.061
85.500	0.068
92.625	0.047
99.750	0.038
106.875	0.032
114.000	0.028
121.125	0.029
128.250	0.024
135.375	0.023
142.500	0.024
149.625	0.024
156.750	0.017
163.875	0.015
171.000	0.016
178.125	0.019
185.250	0.018
192.375	0.011
199.500	0.000
206.625	0.000
213.750	0.000
220.875	0.000
228.000	0.000
235.125	0.000
242.250	0.000
249.375	0.000
256.500	0.000

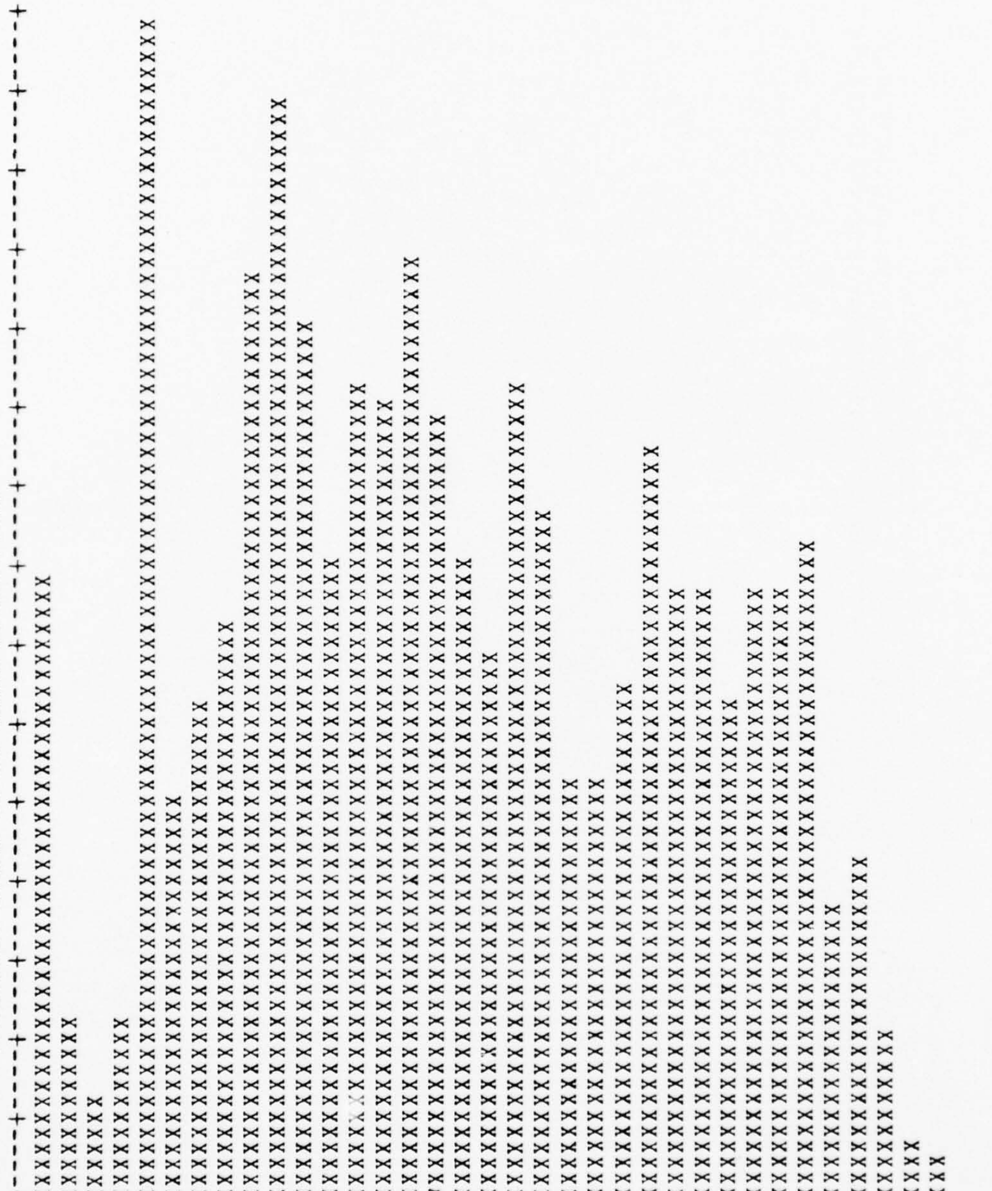
FIGURE 8.18 RUN 003

NORMALIZED TARGET REPORT RANGE DISTRIBUTION

RANGE (nm)	PERCNT
0.000	0.021
7.125	0.012
14.250	0.005
21.375	0.013
28.500	0.062
35.625	0.174
42.750	0.099
49.875	0.049
57.000	0.054
64.125	0.101
71.250	0.080
78.375	0.059
85.500	0.069
92.625	0.063
99.750	0.060
106.875	0.036
114.000	0.015
121.125	0.010
128.250	0.006
135.375	0.005
142.500	0.005
149.625	0.001
156.750	0.001
163.875	0.000
171.000	0.000
178.125	0.000
185.250	0.000
192.375	0.000
199.500	0.000
206.625	0.000
213.750	0.000
220.875	0.000
228.000	0.000
235.125	0.000
242.250	0.000
249.375	0.000
256.500	0.000

FIGURE 8.19 RUN 005

NORMALIZED TARGET REPORT RANGE DISTRIBUTION



RANGE (nm)	PERCNT
0.000	0.031
7.125	0.009
14.250	0.006
21.375	0.010
28.500	0.058
35.625	0.020
42.750	0.025
49.875	0.029
57.000	0.046
64.125	0.055
71.250	0.044
78.375	0.032
85.500	0.041
92.625	0.040
99.750	0.047
106.875	0.039
114.000	0.032
121.125	0.028
128.250	0.040
135.375	0.034
142.500	0.021
149.625	0.021
156.750	0.026
163.875	0.038
171.000	0.031
178.125	0.030
185.250	0.025
192.375	0.031
199.500	0.031
206.625	0.033
213.750	0.015
220.875	0.018
228.000	0.009
235.125	0.004
242.250	0.002
249.375	0.000
256.500	0.000

NORMALIZED TARGET REPORT RANGE DISTRIBUTION

```
RANGE(nm)  PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
   0.000   0.045  /XXXXXXXXXXXXXXXXX
   7.125   0.150  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  14.250   0.191  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  21.375   0.191  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  28.500   0.102  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  35.625   0.044  /XXXXXXXXXXXXXXXXX
  42.750   0.032  /XXXXXXXXXXXX
  49.875   0.026  /XXXXXXXXXX
  57.000   0.024  /XXXXXXXXX
  64.125   0.033  /XXXXXXXXXXXXX
  71.250   0.023  /XXXXXXXXX
  78.375   0.014  /XXXXX
  85.500   0.009  /XXX
  92.625   0.007  /XX
  99.750   0.004  /X
 106.875   0.003  /
 114.000   0.003  /X
 121.125   0.005  /XX
 128.250   0.007  /XX
 135.375   0.012  /XXXX
 142.500   0.017  /XXXXXX
 149.625   0.017  /XXXXXX
 156.750   0.017  /XXXXXX
 163.875   0.013  /XXXXX
 171.000   0.004  /X
 178.125   0.002  /
 185.250   0.005  /X
 192.375   0.000  /
 199.500   0.000  /
 206.625   0.000  /
 213.750   0.000  /
 220.875   0.000  /
 228.000   0.000  /
 235.125   0.000  /
 242.250   0.000  /
 249.375   0.000  /
 256.500   0.000  /
```

FIGURE 8.20 RUN 006

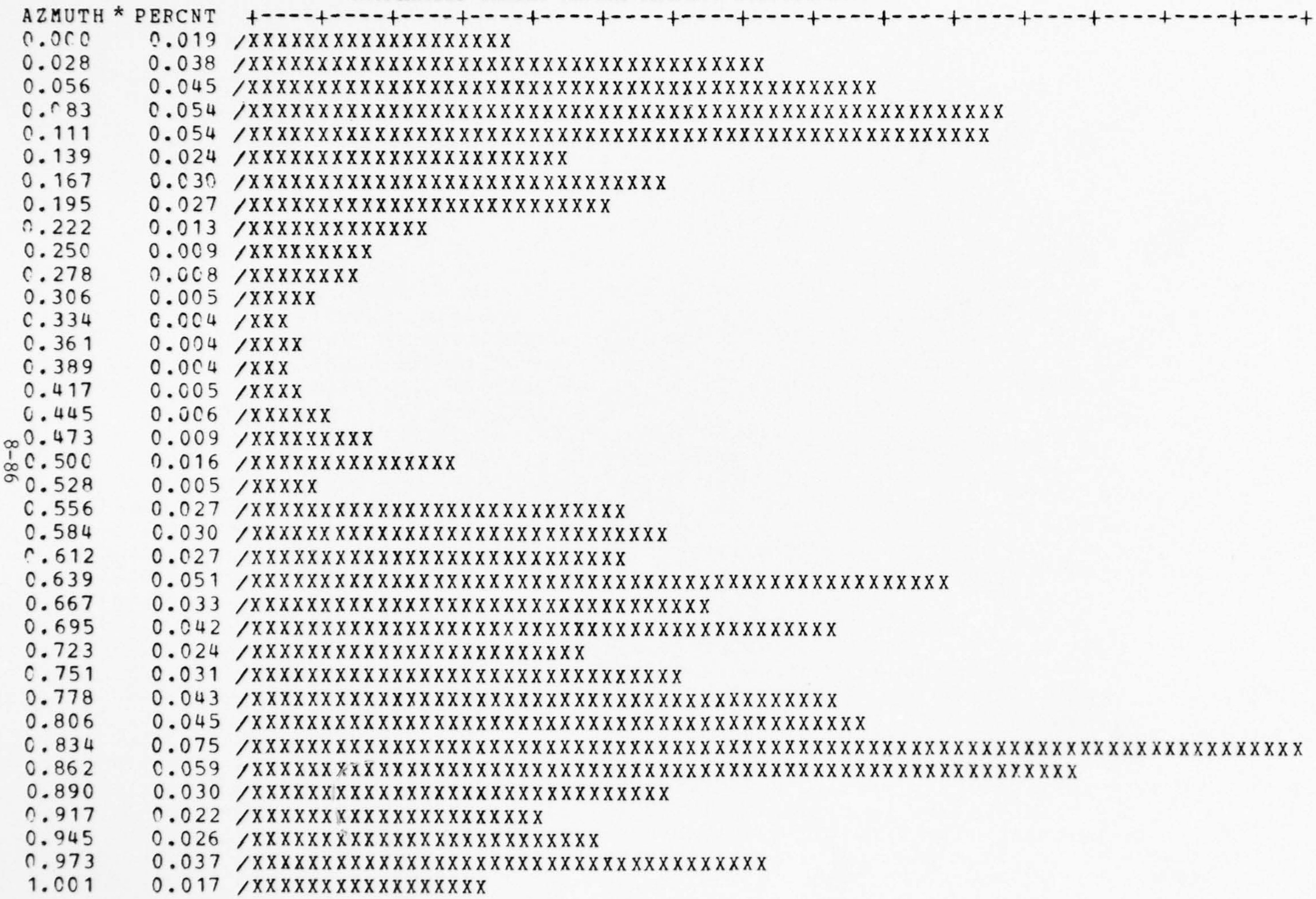
FIGURE 8.21 CDR-809

NORMALIZED TARGET REPORT RANGE DISTRIBUTION

RANGE (nm)	PERCNT
0.000	0.001
7.125	0.055
14.250	0.052
21.375	0.046
28.500	0.053
35.625	0.047
42.750	0.060
49.875	0.048
57.000	0.045
64.125	0.050
71.250	0.045
78.375	0.038
85.500	0.046
92.625	0.045
99.750	0.035
106.875	0.039
114.000	0.038
121.125	0.035
128.250	0.029
135.375	0.029
142.500	0.027
149.625	0.027
156.750	0.020
163.875	0.016
171.000	0.016
178.125	0.014
185.250	0.011
192.375	0.011
199.500	0.010
206.625	0.009
213.750	0.003
220.875	0.000
228.000	0.000
235.125	0.000
242.250	0.000
249.375	0.000
256.500	0.000

FIGURE 8.22 RUN 001

NORMALIZED TARGET REPORT AZIMUTH DISTRIBUTION

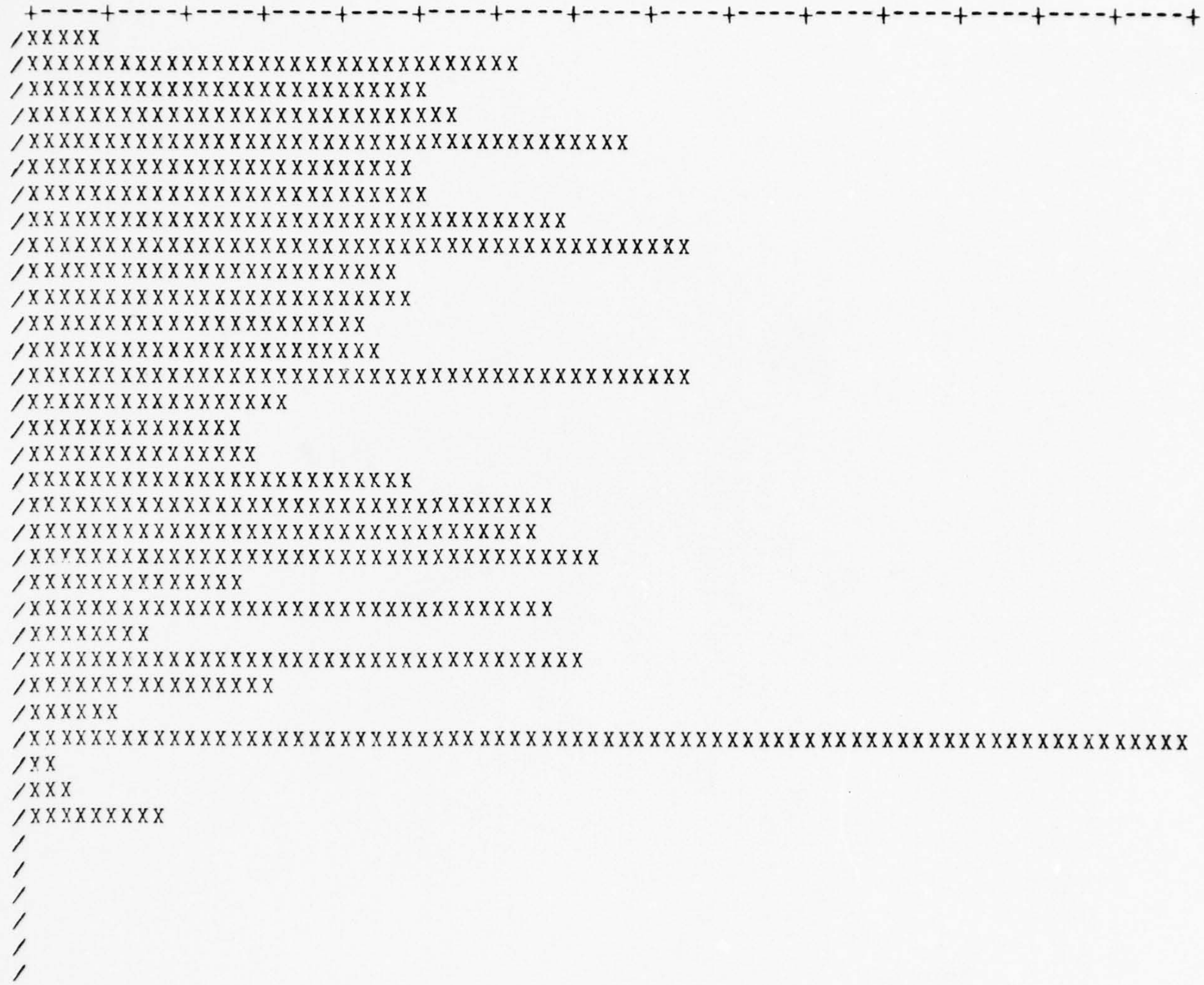


*Azimuth: Multiply by 360 to obtain azimuth in degrees
Multiply by 2π to obtain azimuth in radians
Multiply by 4096 to obtain azimuth in ACP's

FIGURE 8.23 RUN 001

NORMALIZED TARGET ALTITUDE DISTRIBUTION (MODE C ONLY)

ALTITUDE *	PERCNT
0	0.006
13	0.037
26	0.031
39	0.033
52	0.046
65	0.029
78	0.031
91	0.041
104	0.050
117	0.028
130	0.030
143	0.026
156	0.027
169	0.050
182	0.021
195	0.017
208	0.018
221	0.029
234	0.040
247	0.038
260	0.044
273	0.017
286	0.040
299	0.010
312	0.042
325	0.019
338	0.007
351	0.087
364	0.003
377	0.004
390	0.012
403	0.000
416	0.000
429	0.000
442	0.000
455	0.001
468	0.000



*Altitude: (hundreds of feet)

on the plots are given in hundreds of feet. This distribution tends to favor the lower altitude. Figure 8.24 is the altitude distribution for RUN 003 and has an entirely different shape. Figure 8.25 is the altitude distribution for RUN 04A. No particular altitude appears to be strongly favored in this data although a small tendency to favor lower altitude is observed. The altitude distributions for all the other tapes tend to fit one of these three characteristic shapes. In general, it can be said that no typical altitude distribution exists.

As expected, no particular distribution of aircraft in range, azimuth, or altitude is typical. Factors, such as time of day and weather conditions, terrain features, and local traffic trends at each site affect these distributions. Quite often, a typical distribution is arbitrarily assumed for some analysis requiring positional information on targets. The data presented here should be carefully considered when one is considering making such an assumption.

8.4.2.2 FR-950 Quality Check

It was noted previously that steps were taken to compare CD-Records made from real time video with CD-Records made from an FR-950 recording of the same video, and also to compare CD-Records made from an FR-950 played back at different times. Table 8.11 listed the total target reports and the average number of target reports per scan determined by analyzing the CD-Records over comparable ranges and times for each group of tapes that can be compared. Some differences were noted. A comparison of some of the CD-Record report data was done visually by overlapping the report data from the tapes to be compared on the color TV display and distinguishing the reports from each tape with different colors. The first comparison was made between tapes RUN 04A, RUN 04B and RUN 04C.

Recall that RUN 04A was made by playing real time beacon video through the Elwood CD on the first trip (February 1975) while an FR-950 video tape was simultaneously being recorded. Immediately afterward on this trip, the FR-950 tape of what should be the same video was played back through the CD twice to produce CD-Record tapes RUN 04B and RUN 04C. Beacon target reports from tape RUN 04A were displayed over an interval of 13 minutes, 21 seconds on the color TV console in green dots. Tape RUN 04C target reports were then displayed on the console over the corresponding time interval in red dots while the RUN 04A display remained. Figure 8.26 is a photograph of the results. The overlapping of red and green dots produces white, red appears as orange, and green appears as blue.

```
                       NORMALIZED TARGET ALTITUDE DISTRIBUTION (MODE C ONLY)
ALTITUDE*   PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
    0       0.000  /
   13       0.015  /XXXXXXXX
   26       0.034  /XXXXXXXXXXXXXXXXXX
   39       0.133  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   52       0.050  /XXXXXXXXXXXXXXXXXXXXXXXXXXXX
   65       0.044  /XXXXXXXXXXXXXXXXXXXXXXXX
   78       0.070  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   91       0.063  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  104       0.053  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  117       0.052  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  130       0.070  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  143       0.031  /XXXXXXXXXXXXXXXXX
  156       0.033  /XXXXXXXXXXXXXXXXXX
  169       0.033  /XXXXXXXXXXXXXXXXXX
  182       0.010  /XXXXX
  195       0.040  /XXXXXXXXXXXXXXXXXXXXXX
  208       0.003  /X
  221       0.005  /XXX
  234       0.000  /
  247       0.000  /
  260       0.000  /
  273       0.000  /
  286       0.000  /
  299       0.000  /
  312       0.000  /
  325       0.000  /
  338       0.000  /
  351       0.000  /
  364       0.000  /
  377       0.000  /
  390       0.000  /
  403       0.000  /
  416       0.000  /
  429       0.000  /
  442       0.000  /
  455       0.000  /
  468       0.000  /
```

*Altitude (hundreds of feet)

FIGURE 8.25 RUN 04A

```
                                   NORMALIZED TARGET ALTITUDE DISTRIBUTION (MODE C ONLY)
ALTITUDE*  PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
    0      0.001 /
   13      0.013 /XXXXXXXXXX
   26      0.019 /XXXXXXXXXXXXXX
   39      0.021 /XXXXXXXXXXXXXXXX
   52      0.031 /XXXXXXXXXXXXXXXXXXXXXXXX
   65      0.082 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   78      0.054 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   91      0.044 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  104      0.070 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  117      0.023 /XXXXXXXXXXXXXXXXXX
  130      0.017 /XXXXXXXXXXXXX
  143      0.042 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  156      0.055 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  169      0.023 /XXXXXXXXXXXXXXXXX
  182      0.025 /XXXXXXXXXXXXXXXXXXX
  195      0.019 /XXXXXXXXXXXXXXX
  208      0.009 /XXXXXX
  221      0.013 /XXXXXXXXX
  234      0.016 /XXXXXXXXXXXX
  247      0.029 /XXXXXXXXXXXXXXXXXXXXXX
  260      0.029 /XXXXXXXXXXXXXXXXXXXXXX
  273      0.027 /XXXXXXXXXXXXXXXXXXXX
  286      0.025 /XXXXXXXXXXXXXXXXXXX
  299      0.007 /XXXXX
  312      0.050 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  325      0.037 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  338      0.011 /XXXXXXXX
  351      0.096 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  364      0.023 /XXXXXXXXXXXXXXXXX
  377      0.014 /XXXXXXXXXXX
  390      0.015 /XXXXXXXXXXX
  403      0.000 /
  416      0.008 /XXXXXX
  429      0.000 /
  442      0.000 /
  455      0.000 /
  468      0.000 /
```

*ALTITUDE (hundreds of feet)

FIGURE 8.26 COMPARISON OF FR-950 DATA WITH REAL TIME

RUN 04A - RUN 04C

* RUN 04A - GREEN (REAL TIME)
  13:34:00 - 14:47:21

* RUN 04C - RED (FR-950)
  15:42:39 - 15:56:00

* 75 NMI RINGS

AD-A038 492 JOHNS HOPKINS UNIV LAUREL MD APPLIED PHYSICS LAB F/G 17/7
SYSTEM DEFINITION AND INVESTIGATION OF ON-SITE PROCESSING OF EN--ETC(U)
SEP 76 J W THOMAS DOT-FA75WA-3553
UNCLASSIFIED APL/JHU-FP8-E-024-2 FAA-RD-77-12-2 NL

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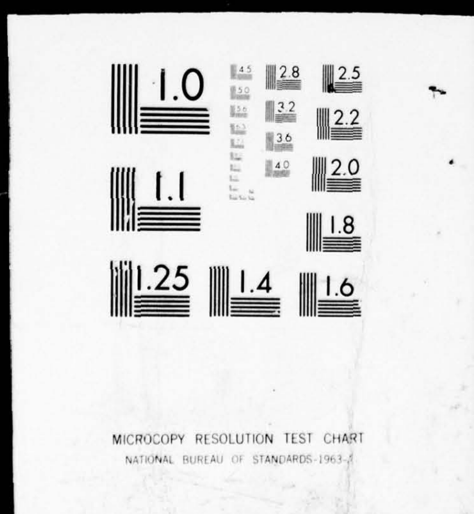


The tracks of RUN 04A and RUN 04C largely coincide producing the mass of white tracks. There are a few green reports indicating some reports on RUN 04A are not on RUN 04C. More important, however, are the red reports which appear, indicating that tape RUN 04C has some extra targets which did not appear on the real time tape RUN 04A. There is a significant number of these red reports which do not have a corresponding green report. Figure 8.27 is a similar display of tape RUN 04A and RUN 04B. All tracks of Figure 8.27 have a green segment, because several scans of reports from tape RUN 04B which are displayed in red are missing as a result of temporary CD problems. This problem was a result of a failure in the CD ranging and was signaled during the data collection run by the range alarm on the CD (see Section 8.2.4). It probably occurred because the CD missed a trigger from the FR-950 tape. Interestingly, the extra red reports occur again with RUN 04B, and are even in the same general locations as RUN 04C indicating that RUN 04B and RUN 04C are similar to each other. This is reflected by Table 8.11 which indicates that the average number of targets per scan on tapes RUN 04B and RUN 04C are the same (133) while RUN 04A has only 121 reports per scan.

A similar comparison was made between CDR-809 made with real time video and CDR-812 made with FR-950 video. A photograph of the results is present in Figure 8.28. CDR-809 reports were displayed in green while CDR-812 reports were displayed in red. It is apparent that more green only dots appear than red only dots meaning, probably, that CDR-809 has more reports than CDR-812. A check with Table 8.11 shows that this is the case. In this instance, the missing reports from both CDR-812 and CDR-809 generally appear to be part of tracks* which are receiving reports from both tapes for at least part of the track. This feature is not so clearly apparent in the comparison of RUN 04A with RUN 04B and RUN 04C where it cannot, by inspection of the photographs, be determined if the extra reports are part of tracks. The targets can be redisplayed and hooked to determine characteristics but this was not done in the original analysis.

No particularly enlightening information can be extracted from these comparisons. It can be noted that the tracks largely coincide, showing that the target report data comes from essentially the same video. In one case the missing or extra reports are on observable tracks, indicating that perhaps a change in the gain occurred so that weaker replies were missed during one of the runs. In the other case, the extra reports may, in fact, be noise but this has not been confirmed.

---

* The "tracking" is done by the viewer.

FIGURE 8.27 COMPARISON OF FR-950 DATA WITH REAL TIME

RUN 04A - RUN 04B

* RUN 04A - GREEN (REAL TIME)
  13:34:00 - 14:47:21

* RUN 04B - RED (FR-950)
  15:18:56 - 15:32:17

* 75 NMI RINGS

FIGURE 8.28 COMPARISON OF FR-950 DATA WITH REAL TIME

CDR-809 - CDR-812

* CDR-809 - GREEN (REAL TIME)
  10:54:00 - 11:14:00

* CDR-812 - RED (FR-950)
  13:30:50 - 13:50:50

* 75 NMI RINGS

8.4.2.3 Impact of Suspected FR-950 Problem

Although the use of FR-950 video may affect results obtained, it is not considered a major problem to the overall objective of the beacon performance analysis, which is to locate deficiencies in beacon processing. For example, ambiguities are one of the selected problems. The ambiguity rate for a certain type of ambiguity (range splits) is shown to be different for FR-950 video than real time video (Section 8.4.3). However, in both cases, this type of ambiguity is occurring in significant quantities. The fact that the results are different provides the useful information that the video characteristics affect the rate of occurrence of this type of ambiguity. Thus the analysis proceeded with due consideration of observed FR-950 difference given where appropriate. It is, however, recommended that the cause of the observed differences be determined because of its potential impact on future investigations.

8.4.3 Analysis of Target Report Ambiguities

A target report ambiguity occurs when a single aircraft results in the generation of two or more target reports in the same scan by the CD. Ambiguities are a significant problem for several reasons. First is the increased loading of the MODEM lines which carry target report information from the en route ARSR site to the ARTCC. The ambiguous reports, in addition to wasting space in the MODEM lines, also add to data that the 9020 computer system at the ARTCC must process. The display of these ambiguous reports to the controller is at best confusing. The controller must, as a minimum, observe that the ambiguous reports are false, and make a decision to ignore them. The situation is more critical if the controller cannot determine which of the ambiguous reports is the real aircraft position or if he does not realize that ambiguous reports are present. For these reasons, target report ambiguities are considered a problem which warrants further consideration.

As the definition of ambiguities states, an ambiguity is the occurrence of two or more target reports in the same scan resulting from a single aircraft. Thus, an ambiguity may consist of two reports or more than two reports. The target reports shall be called elements of the ambiguity. Together, the elements comprising an ambiguity shall be called an ambiguity group. The group size is the number of elements in the group. Ambiguities with a group size of two can also be called pairs and larger groups may be called non-pairs.

The ambiguity detection function of TRAAP was first used with the CD record target report display to flag the ambiguous reports for visual analysis. In general, it was observed that there are five identifiable categories of ambiguities based on separation existing between the ambiguous target reports. These classes are:

1. Range Splits
2. Azimuth Splits
3. Sidelobe Ambiguities
4. Reflection Outside the Mainbeam
5. Mainbeam Reflections

For non-pairs, the range separation and azimuth separation used to classify the ambiguity are the maximums that exist between any two reports in the group. Absolute values are always used. For pairs, the target report with the closest range is chosen as an arbitrary reference, making the range separation always positive. The azimuth separation is measured from the reference report and may be positive or negative depending upon the direction of the displacement. When the separations are discussed numerically, absolute values are almost always used (i.e., a separation of 3° simply implies that the reports are 3° apart). The only time that the sign of the separation is used is when the normalized frequency of azimuth separations is plotted.

Although the ambiguities are classified according to their range and azimuth separations, this factor is closely related to the mechanism that generated them. It is this mechanism that is of primary concern. In consideration of this, the discussion of the characteristics of the ambiguities will be closely tied to the mechanisms for generating them. In some instances the ambiguities separation characteristics were first observed, then the mechanism for generation was hypothesized. In other cases, the ambiguities were known to exist and the cause was already known.

Range splits were observed to occur in pairs separated by less than (usually) 3° in azimuth and 0.125 nmi in range. Less frequently, they occurred separated by 0.250 nmi.

Range splitting is observed for targets that are part of easily distinguished tracks. This, coupled with the 3° azimuth separation which is approximately a beamwidth, indicates that the range split is generated entirely during the mainbeam. The distribution of azimuth separations for range splits, presented later in this section, shows that the azimuth separation most favored is 0°. Since two target reports cannot be in the same range cell at the same azimuth, this is evidence that the range split elements indeed are generated in adjacent range cells. The range cells are 1/4 nmi, but target report range in a range cell is reported to the nearest 1/8 nmi (upper or lower half of a range cell), thus targets separated by an 1/8 nmi can be in adjacent range cells. Although a single aircraft is generating the replies used to form the report, the replies may fall in different range cells if the target lies sufficiently close to a range cell boundary for inherent system range jitter to cause the replies to jump between range cells. This is assumed to be the basis for range split generation. The replies from a single target are randomly being placed by the CD in one of two adjacent range cells in sufficient quantities to declare a target present in both range cells. The characteristics of range splits are that they generally occur in pairs, fall in adjacent range cells with an associated range separation usually of an 1/8 nmi but sometimes 1/4 nmi, and are generated during a mainbeam interrogation with a corresponding azimuth separation of usually less than 3°.

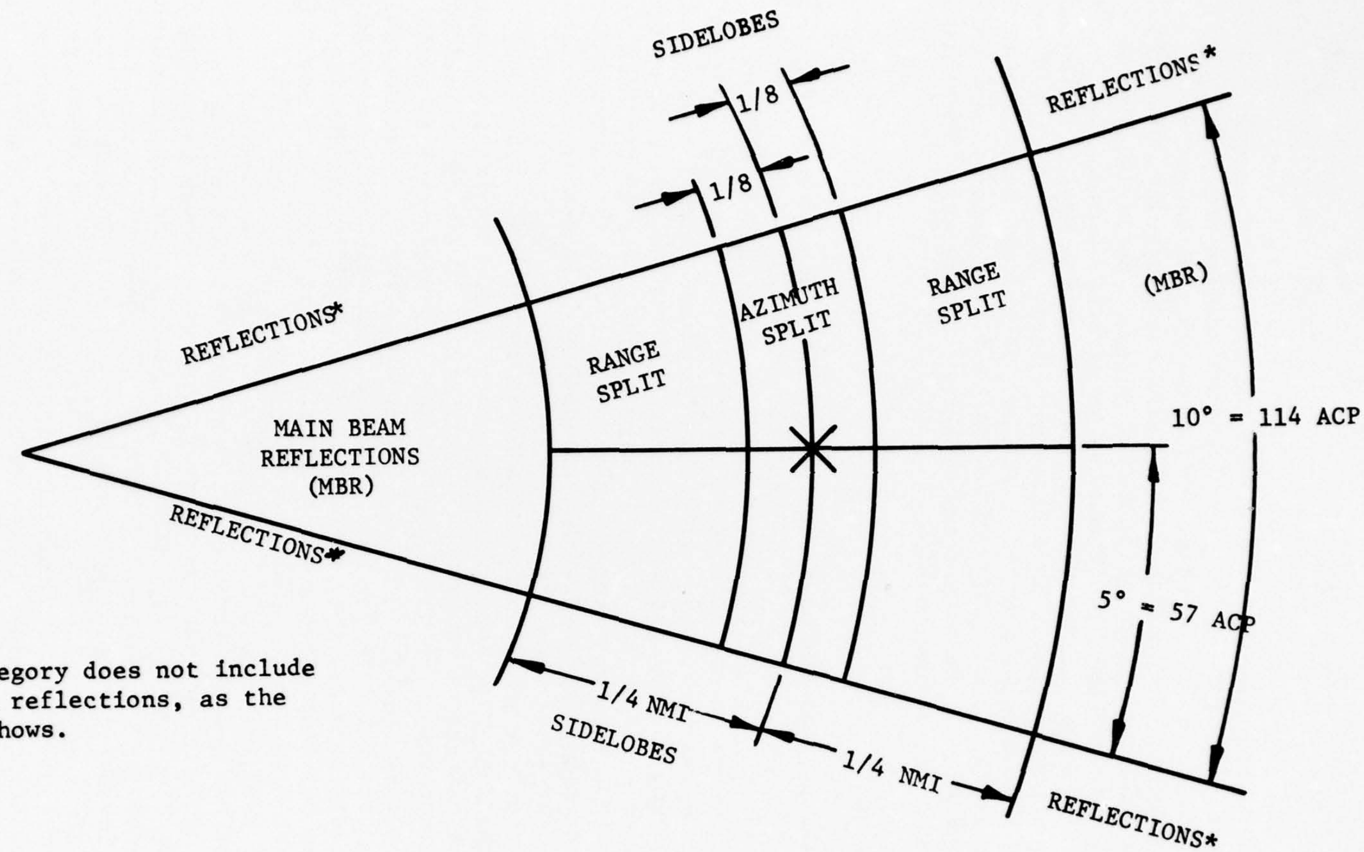
The mechanism for generating an azimuth split was assumed to be a fading of beacon replies and subsequent strengthening again of the replies while the target is being interrogated in the mainbeam. The fading of replies must be sufficient to declare a target report complete, then, enough strong replies must be received to declare a new target report before the actual aircraft is out of the mainbeam. In this case all the replies are assumed to be placed in the same range cell. Thus, azimuth splits will have the same range and, since they occur during a mainbeam interrogation, be separated by no more than about 3°. They were observed to occur exclusively in pairs.

Sidelobe ambiguities result when target reports are generated by a single aircraft through interrogation by two or more of the antenna lobes. This will normally include the mainbeam interrogations and interrogations through one or more sidelobes. Normally, the reports will be generated at the same range. However, the time between generation of sidelobe elements is much greater than that of range or azimuth splits since the antenna has turned through more than the 3° of mainbeam beamwidth and, if a target has a radial velocity to or from the sensor, the range may change slightly between the generation of successive elements forming a sidelobe ambiguity. Thus sidelobes occur at azimuth separation larger than a beamwidth and at almost the same range. Sidelobes usually occur in pairs, but are more likely than the other ambiguities to occur in larger group sizes, as observed from the data.

Reflections are generated when an aircraft is interrogated by the mainbeam via a reflecting surface, and replies through a sidelobe. The report generated by the reflected interrogations along with the normally generated target report, form an ambiguity pair. Reflections will be at different ranges because of the different interrogator/reply path length, different azimuth because the mainbeam is not pointed at the target at all during generation of the reflected report, and occur mostly in pairs.

Mainbeam reflections have a large range separation but occur in the mainbeam. They are almost always in pairs. The use of the term "reflection" for this type of ambiguity may be a misnomer because they may not be caused by a reflection phenomena at all. The term "mainbeam reflection" was given to these ambiguities before their cause had been determined. There is evidence to indicate that they are generated in much the same way that range splits are generated, though the range cells are no longer adjacent. An analysis of system range jitter shows that very large deviations are possible though unlikely. Mainbeam reflections were quite rare.

The TRAAP program, after detection of an ambiguity group, classifies the ambiguity into one of these five categories. The algorithm used was based on the characteristics of the ambiguities which were observed using the display system and is illustrated by Figure 8.29. The illustration depicts the regions of range and azimuth separation from a reference target report, marked by the X, for each classification. For example, range splits have an azimuth separation normally less than 3°. On occasion however, the azimuth separation was observed to be greater. In addition, range splits must lie in adjacent range cells (by definition) so that they have a range separation of either an 1/8 nmi or a 1/4 nmi. The region designated range splits in Figure 8.21 illustrates the 5° azimuth separations and the 1/8 to 1/4 nmi range separations. Azimuth splits must have zero range separation and be less than 5° apart in azimuth. The resolution of the ranging is 1/8 nmi, so that the region for azimuth splits in Figure 8.29 is shown as being less than 1/8 nmi from the X and inside of 5° from it.



*This category does not include mainbeam reflections, as the figure shows.

FIGURE 8.29

ILLUSTRATION OF SEPARATION CRITERIA USED IN ALGORITHM TO CLASSIFY AMBIGUITIES

Range and azimuth splits are generated within the time it takes the mainbeam to sweep a beamwidth (~3°). Sidelobe ambiguities may be generated over a longer period of time. Consequently, the target may cross a range bin during the generation of a sidelobe ambiguity, resulting in target reports being generated at different ranges. Normally, only a single range cell boundary will be crossed by an aircraft during the generation of sidelobe ambiguities in one scan. Thus, the region indicated for sidelobes is greater than 5° separation in azimuth and up to a 1/4 nmi. Those ambiguities have a separation of more than 1/4 nmi and greater than 5° are classified as reflections. This leaves the region of separation within the mainbeam, or within 5°, but separated by more than 1/4 nmi. These have been classified mainbeam reflections.

8.4.3.2 Data Tables

The TRAAP program was used to classify the ambiguities on the collected CD Record tapes. Table 8.12 lists the tapes analyzed, the start and stop times, and start and stop ranges used for the analysis and the total number of discrete beacon code target reports that occurred. Ambiguities were detected by setting the maximum allowable range and azimuth separation parameters in TRAAP at 256 nmi and 180° respectively and selecting the duplicate discrete code option. Thus, any group of reports occurring on the same scan with the same discrete code was flagged as an ambiguity in the target report data. The detected ambiguities were then categorized into one of the five classifications. The results as printed out by TRAAP for each run are tabulated into categories as shown by Table 8.13 for RUN 001. Each entry in the table is the number of ambiguities that occurred which fit into that category. All the categories are mutually exclusive. The ambiguity categories are listed across the top as column headers. Each row designates an additional breakdown within the ambiguity category. As noted previously, even though two or more targets should not have the same discrete code within the coverage of the radar-discrete sensors, they sometimes do. An additional distinguishing characteristic besides discrete beacon codes is altitude which is present for those targets which have Mode C transponder equipment. It is not likely that two aircraft with the same Mode 3/A code will also have the same altitude. A number of possibilities exist when Mode C altitude data is collected. Some ambiguities, such as range splits, even though resulting from aircraft with Mode C equipment, may occur in groups of two or more in which only one report actually got a Mode C altitude. Also possible is for the group to have at least two Mode C reports but not all Mode C reports. Finally, all reports in a group can have a Mode C altitude. Whenever at least two Mode C reports occur, a check for duplicate altitude can be made. Another feature of ambiguities to consider is the number of reports in a group. The ambiguities usually occur in groups of two though some, such as sidelobes, will be more likely to occur in larger groups than others. The ambiguities are put into categories that reflect these considerations as shown by Table 8.13.

TABLE 8.12

TAPES ANALYZED - DUPLICATE DISCRETE CODE ANALYSIS OF AMBIGUITIES

TAPE	ANALYSIS TIME		ANALYSIS RANGE		NUMBER OF DISCRETE REPORTS
	START	STOP	START	STOP	
RUN 001	9:51:01	10:11:01	11	188	12303
RUN 002	10:58:01	11:16:01	0	256	9400
RUN 003	13:08:00	13:28:00	0	256	5471
RUN 04A	13:34:00	14:47:21	11	188	10008
RUN 04B	15:18:56	15:32:17	11	188	9462
RUN 04C	15:42:39	15:56:00	11	188	11003
RUN 009	10:12:24	10:26:24	11	245	2051
RUN 006	11:18:00	11:39:00	0	256	3144
CDR-804	14:33:21	14:53:21	11	188	10082
CDR-805	15:06:57	15:24:57	0	256	9347
CDR-807	9:41:21	9:54:42	11	188	7147
CDR-809	10:54:00	11:14:00	11	210	7147
CDR-810	11:23:00	11:43:00	11	210	9127
CDR-811	13:00:00	13:15:00	11	210	7741
CDR-812	13:30:50	13:50:50	11	210	13174

TABLE 8.13

BREAKDOWN OF AMBIGUITIES - RUN 001
(See Table 8.12 for analysis limits)

TOTAL REPORTS: 12303
TOTAL AMBIGUITIES: 683

	RANGE SPLITS	MAIN BEAM REFLECTIONS	SIDE LOBES	REFLECTIONS*	AZ SPLITS
NON MODE C					
PAIRS:	27	0	0	3	1
NON PAIRS:	0	0	0	0	0
ONE MODE C ONLY					
PAIRS:	250	11	38	28	2
NON PAIRS:	1	0	2	2	0
NON PAIRS, MORE THAN ONE MODE C BUT NOT ALL MODE C					
DUP ALT:	1	0	3	0	0
NON DUP ALT:	0	0	0	3	0
ALL MODE C					
PAIRS					
DUP ALT:	179	0	25	1	1
NON DUP ALT:	3	0	4	90	0
NON PAIRS					
DUP ALT:	0	0	6	2	0
NON DUP ALT:	0	0	0	0	0

<u>IMPORTANT</u>:
Read Section 8.4.3.2 for correct interpretation of this data.

*Does not include mainbeam reflections

First, all groups having no Mode C reports are broken into pairs and non pairs. Then, those groups having just one Mode C report are broken into pairs and non pairs. Groups which have at least two Mode C reports but at least one non Mode C report, (which must necessarily be non pairs) are broken into those which have at least one pair of matching altitudes (duplicate altitude) and those which have no matching altitudes (non duplicate altitudes). Finally, those groups which are all Mode C are broken into pairs; duplicate and non duplicate altitude and non pairs; duplicate and non duplicate altitude. To determine the percentage of splits occurring in each category, the number entered in the table is divided by the total number of discrete reports occurring in the analysis interval given in Table 8.12.

Certain interesting features about ambiguities are indicated by Table 8.13. For example, it is evident, under the range split column, that the majority of range splits are pairs. Looking across the table, one sees that range splits are the most frequently occurring ambiguity. Of the range split pairs which were both Mode C reports (all Mode C, pairs), almost all had duplicate altitude, giving a high degree of confidence that these are, in fact, two reports coming from the same target. Also, a large number of range splits had only one Mode C report in the pair. This was a characteristic which was first observed from the display; i.e., frequently, when a Mode C equipped target generates a range split pair one of the reports will not have a Mode C altitude. The reason for this can be determined by considering the beacon reply group processing in the CD. Target reports are generated by placing the received replies in a sliding window corresponding to the appropriate range cell. When sufficient Mode 3/A replies are received in the window, a beacon target report is declared. When sufficient Mode C replies are received, an altitude is computed for the target. With normal interlace patterns, such as 3/A, 3/A, C, more 3/A replies are received from a target than Mode C replies. It is suspected that range splits result when jitter in the beacon ranging system (see Section 4.2) causes the replies from a target to randomly jump between adjacent range cells. Thus a fixed number of replies are divided (not necessarily equally) between two range cells. Because there are more Mode 3/A replies than Mode C replies, there may be a sufficient number of them to declare a target report in both range cells while an insufficient number of Mode C replies exist to validate an altitude in both cells. If the sharing of the replies is unequal, one cell may validate an altitude while the other does not. Consequently, a large number of range splits have only one Mode C report.

The mechanism for generating mainbeam reflections has not been formulated. The data collected tends to imply that the term, "reflection", may indeed be a misnomer. It should be observed, for example, that all the mainbeam reflections had only one Mode C report in Table 8.13. In all the data analyses run, mainbeam reflections were found to reflect this trend strongly; i.e., a majority had one Mode C report and one non Mode C report. This suggests that the mechanism involved results in one of the reports losing Mode C

information. The sharing of replies between range cells that was described for range split generation would produce this effect. In range split generation the replies are adjacent range cells. Perhaps mainbeam reflections are generated by the same mechanism but with a larger range jitter involved so that the range cells are not adjacent. The range jitter present in the system is described statistically in Section 4.2 and it is possible for very large range deviations to occur, putting replies in range cells that are not adjacent.

A significant contribution to ambiguities is sidelobes. Notice that for RUN 001, the sidelobes are mostly in pairs. Like the range splits, the sidelobes which have two or more Mode C reports in the group almost always have duplicate altitudes which indicates that real ambiguities are being detected. A large number of them also have only one Mode C reply. Sidelobes are generated by interrogation and replies occuring through the sidelobe and are usually at almost the same range, but different azimuths. Since the sidelobe antenna gain is lower than the mainlobe, it may be expected that the effective beamwidth over which replies occur, and consequently the number of replies that occur on a sidelobe, will be less than for the mainbeam. Thus while enough Mode 3/A replies are received to declare a target report, there may be insufficient Mode C replies to validate an altitude for the report that was generated by the sidelobe replies.

A significant number of reflections were also detected. However, notice that of the 96 reflections that have at least two Mode C reports, 90 of them do not have a duplicate altitude, indicating that the "reflections" are actually two aircraft squawking the same discrete beacon code but flying at different altitudes. It is assumed that interrogations arriving at the transponder and/or replies arriving at the antenna via a reflecting surface are the cause of the reflections. As for the 33 ambiguities which have one or no Mode C reports, it cannot be determined that these are or are not true ambiguities from these statistics. However, because almost all the "reflections" with more than one Mode C report had non duplicate altitudes indicating two actual targets, it is probable that most of the 33 "ambiguities" are a result of two aircraft squawking the same code, but only one equipped with a Mode C transponder.

The remaining category is azimuth splits. Since azimuth splits are required to be at the same range and be separated in azimuth by a beamwidth or less, a target leading edge, trailing edge, and leading edge must be declared within the mainbeam interrogation time. It is assumed that this occurs because of a loss of replies so that a trailing edge is declared during interrogations by the mainbeam followed by a subsequent regaining of replies during the interrogations in sufficient quantity to declare another target leading edge. Table 8.13 shows the azimuth splits are very rare.

All of the analysis runs showed the same general trends in data that are pointed out for RUN 001. For range splits, sidelobe splits, and mainbeam reflections, the majority of ambiguities which had at least two Mode C reports in the group also had duplicate altitudes. The majority of the ambiguities in these three categories, however, occurred in pairs having one Mode C report and one report for which Mode C data was missing. The reason, detailed in the above discussion, is related to the fact that one of the pair of reports was generated from fewer replies than the other report. As there are usually more Mode 3/A replies than Mode C replies, due to the mode interlace normally used, there is often a sufficient number of replies to declare two reports but not enough to have Mode C data present for both. In all the tapes made for this analysis, with the exception of RUN 006, the interlace used had more Mode 3/A interrogation than Mode C interrogations (see Tables 8.2, 8.3 and 8.4). In RUN 006, the interlace was (3/A,C) so that an equal number of Mode 3/A and Mode C replies should occur. For this run alone, the majority of the ambiguities occurring in the range split, mainbeam reflections, and sidelobe categories consist of two reports, both with Mode C, and duplicate altitude. This is very good evidence that the theories proposed for generation of these ambiguities and losses of Mode C information are reasonable. Table 8.14 presents the ambiguity data collected for RUN 006.

For each of the analyses done, the entries in each column were totaled and divided by the total number of target reports to compute the detected ambiguity rate. The results are tabulated in Table 8.15. In the discussion of the results for RUN 001 above, the occurrence of duplicate altitude for those ambiguities which had at least two Mode C reports was used as a measure of confidence that "real" ambiguities were being detected, rather than just two or more targets with the same duplicate discrete code. This measure was quantified where possible by computing the ratio of duplicate altitude ambiguities of all ambiguities in each category with two or more Mode C reports. The results are tabulated in Table 8.16. These numbers can be considered as an estimate of the probability that any detected ambiguity in the associated category is "real" rather than two or more targets with the same duplicate discrete code. In some cases, no Mode C data occurred, so that the ratio could not be computed. The figures in Table 8.15 can be thought of as an estimate of the probability of detecting an ambiguity (given in percentage) and the figures in 8.16 are the probabilities that a detected ambiguity is a "real" ambiguity. Therefore the product of these two numbers is the probability of a real ambiguity. The product was computed in each case where possible to produce the results given in Table 8.17 called adjusted ambiguity rates.

In Table 8.15, the detected ambiguity rates are listed. Things to be noted from this table are that mainbeam reflections and azimuth splits are almost negligible, while range splits, sidelobes, and reflections occur

TABLE 8.14

BREAKDOWN OF AMBIGUITIES - RUN 006
(see Table 8.12 for analysis limits)

TOTAL REPORTS: 3144
TOTAL AMBIGUITIES: 115

	RANGE SPLITS	MAIN BEAM REFLECTIONS	SIDE LOBES	REFLECTIONS*	AZ SPLITS
NON MODE C					
PAIRS:	2	0	1	2	0
NON PAIRS:	0	0	0	0	0
ONE MODE C ONLY					
PAIRS:	12	2	6	0	0
NON PAIRS:	0	0	0	0	0
NON PAIRS, MORE THAN ONE MODE C BUT NOT ALL MODE C					
DUP ALT:	0	0	2	0	0
NON DUP ALT:	0	0	0	0	0
ALL MODE C					
PAIRS DUP ALT:	55	4	18	4	0
NON DUP ALT:	1	2	0	1	0
NON PAIRS DUP ALT:	0	1	2	0	0
NON DUP ALT:	0	0	0	0	0

*Does not include mainbeam reflections

<u>IMPORTANT:</u>
Read Section 8.4.3.2 for correct interpretation of this table.

TABLE 8.15

AMBIGUITY RATES

TAPE	R	MBR	SL	REF	AZ
RUN 001	3.75	.09	.63	1.05	.03
RUN 002	1.43	.05	.10	1.80	0.00
RUN 003	3.34	0.02	0.04	1.79	0.04
RUN 04A	4.12	.03	0.45	1.94	.06
RUN 04B	2.89	.13	.86	1.99	.06
RUN 04C	2.86	.08	.85	1.86	.04
RUN 005	1.80	.05	0	.05	0
RUN 006	2.23	.29	.92	.22	0
CDR-804	2.35	.22	.12	.36	.01
CDR-805	1.25	.20	1.35	4.58	.09
CDR-807	1.65	0.10	0.62	1.48	0.01
CDR-809	1.25	0.18	0.91	2.87	0.03
CDR-810	.24	.07	.13	2.11	0
CDR-811	1.36	.01	1.07	1.73	.21
CDR-812	1.18	0.09	0.58	2.05	0.14

TABLE 8.16

RATIOS OF DUPLICATE ALTITUDE AMBIGUITIES
TO ALL AMBIGUITIES FOR THOSE GROUPS
WITH TWO OR MORE MODE C REPORTS

TAPE	R	MBR	SL	REF	AZ
RUN 001	.984	NMC	.895	.031	1.0
RUN 002	NMC	NMC	NMC	NMC	NMC
RUN 003	.970	0.0	.571	.929	NMC
RUN 04A	.995	NMC	.750	.106	1.0
RUN 04B	.990	NMC	.800	.094	1.0
RUN 04C	1.00	NMC	.818	.096	1.0
RUN 005	1.00	NMC	NMC	NMC	NMC
RUN 006	.982	.714	1.0	.800	NMC
CDR-804	.990	.200	1.0	.065	1.0
CDR-805	.923	0.0	.949	.128	NMC
CDR-807	.978	.333	.929	.083	NMC
CDR-809	0.966	0.0	.883	.072	1.0
CDR-810	.909	0.0	.857	.008	NMC
CDR-811	NMC	NMC	NMC	NMC	NMC
CDR-812	.980	0.0	.737	.101	1.0

NMC - No Mode C Ambiguities Occurred

TABLE 8.17

ADJUSTED AMBIGUITY RATES

TAPE	R	MBR	SL	REF	AZ
RUN 001	3.69	-	0.56	.03	0.03
RUN 002	-	-	-	-	0
RUN 003	3.24	.01	.37	0.15	-
RUN 04A	4.10	-	0.034	0.21	0.06
RUN 04B	2.86	-	0.69	.019	0.06
RUN 04C	2.86	-	.70	0.18	0.04
RUN 005	1.80	-	0	-	0
RUN 006	2.19	0.21	0.92	0.18	0
CDR-804	2.33	0.00	.12	0.02	.01
CDR-805	1.15	0.00	1.28	0.59	-
CDR-807	1.61	.03	0.58	0.12	-
CDR-809	1.21	0.0	.80	0.21	0.03
CDR-810	0.22	0.0	0.11	0.02	0
CDR-811	-	-	-	-	-
CDR-812	1.16	0.0	.43	0.21	0.14

more frequently. Next consider Table 8.16. A high probability of the detected ambiguity being real is indicated for range splits and sidelobes, while a very low probability exists for reflection. This is because for reflections, as stated before, what is usually being detected are two or more targets squawking the same discrete beacon code. Finally, consider the adjusted ambiguity rates shown in Table 8.17. In most cases range splits are the most significant ambiguity, followed by sidelobes. The other types of ambiguities are almost negligible. Reflections may still cause some concern but these, in fact, are best solved by proper radar setting, and not modification to CD processing. This is because reflections are also site dependent and the problem may be significant at some sites, but not at the sites we analyzed.

One ambiguity characteristic is the number of targets that form an ambiguity group. Table 8.18 tabulates the percentages of ambiguities in each category that are pairs. Azimuth splits are always pairs. This can be explained by the fact that they are required to be in the same range cell and separated by no more than 5° in azimuth. Within this 5° sector, it is not possible to declare two lead edges, two trail edges and another lead edge because there simply aren't enough interrogations. Thus, two is the maximum. Range splits and mainbeam reflection are almost all pairs. Reflections are generally all pairs. This is because most of the detected reflections are two or more targets with the same discrete code. It is unlikely that two targets will have the same discrete code and more unlikely that three targets have the same discrete code. Sidelobes, while still mostly pairs, have a higher observed rate of non pair ambiguities. This would be expected because when sidelobe ambiguities are generated, they may occur at any point during the full 360° scan of the antenna. An extreme case of multiple sidelobe reports is ring around, where a single target produces reports for the full 360° of scan. Generally, the ambiguities are occurring in pairs as shown by the last column in Table 8.18. This is significant because even a low ambiguity rate could be a problem if each ambiguity group consisted of a large number of reports, such as ring arounds do. An example of a phenomena approaching ring around is presented later in this section.

8.4.3.3 Intra-Run Comparison of Rates

For the different CD Record tapes made, system configuration (i.e., FR-950 or real time) and certain parameters were varied. It was observed that these variations affected the detected ambiguity rates.

The first comparison is made between tape RUN 04A, made with real time video, and tapes RUN 04B and RUN 04C made with an FR-950 of the real time video immediately after RUN 04A was made on the same day. The comparison will be made using values from Table 8.11. Notice that the range split rate

TABLE 8.18

PERCENT OF AMBIGUITIES THAT ARE PAIRS

TAPE	RANGE	MBR	SIDELOBES	REF	AZ	TOTAL % PAIR SPLITS
RUN 001	99.6	100.0	85.9	94.6	100.0	97.1
RUN 002	99.3	80.0	88.9	99.4	*	97.2
RUN 003	99.5	100.0	90.9	93.9	100.0	97.1
RUN 04A	99.3	100.0	73.3	87.1	100.0	93.9
RUN 04B	99.3	83.3	76.5	84.0	100.0	90.5
RUN 04C	98.7	88.9	77.7	83.4	100.0	90.4
RUN 005	100.0	100.0	*	100	*	100.0
RUN 006	100.0	88.9	86.2	100	*	95.7
CDR-804	97.0	100.0	91.7	94.4	100.0	96.8
CDR-805	100.0	100.0	34.1	87.6	100.0	80.5
CDR-807	98.3	71.4	81.8	90.6	100.0	93.1
CDR-809	99.0	100.0	72.2	92.7	100.0	90.0
CDR-810	100.0	100.0	91.7	99.5	0	99.1
CDR-811	99.0	100.0	98.8	99.3	100.0	88.0
CDR-812	100.0	100.0	83.1	91.5	100.0	93.2

* No ambiguities of this type occurred for this tape

for RUN 04A is 4.12 percent while for RUN 04B and RUN 04C the rates are almost the same at 2.89 and 2.86 percent respectively. This indicates that the results obtained for the range split rate using the FR-950 tape are repeatable, at least on a short term basis (i.e., the two were made within the same hour), but not necessarily representative of the results obtained from the real time data. The range split rate went down when FR-950 video was used in this case. This is not easily explained.

For sidelobes, the real time rate was 0.45 while the FR-950 rates were 0.86 and 0.85 percent. Again the repeatability of the FR-950 tape results is confirmed but here the sidelobe rate went up for the FR-950 results. It was noted in Section 8.4.2 where RUN 04A, RUN 04B and RUN 04C were analyzed visually, that RUN 04B and RUN 04C had extra target reports present which did not appear to form tracks but, rather, had the characteristics of noise hits. A possible explanation for this is that when the FR-950 video was used the gain was set such that the resulting video amplitude was higher into the CD than it was for the actual real time video into the CD. Recalling that sidelobe ambiguities are generated by receiving replies through the sidelobes of the antenna which have a much lower gain than the mainbeam, it might be hypothesized that some replies which were received, though sidelobes, were not detected in the real time video but, with the increased video amplitude from the FR-950, these same replies become detectable, thereby generating more sidelobe ambiguities.

Reflections are about the same in all three tapes. This is important to note because it was stated before that most of the detected reflections were simply two or more targets which were squawking the same discrete beacon code. The parameter affecting the generation of sidelobes and range splits which are truly false reports would not be expected to affect the generation of real target reports coming from actual targets. The rates of azimuth splits and mainbeam reflections are too small to compare reasonably.

Tape CDR-807 was made on the second APL trip to Elwood, using the same FR-950 tape that was used to make RUN 04B and RUN 04C on the first APL trip. The range split rate for CDR-807 is 1.65 percent as compared to about 2.9 percent for the tapes (RUN 04B and RUN 04C) made on the first APL trip. The sidelobe rate is 0.62 percent compared to 0.85 percent. Reflections are at 1.48 percent compared to about 1.9 percent. Thus on the second APL trip, using the same FR-950, the range split rate and reflections went down while sidelobes went up. The two tapes made from the same FR-950 on the same day had about the same results but CDR-807, made on the second APL trip, had different results, particularly as far as range splits are concerned. In fact, a look at the range split rates for all the runs shows that generally, those rates obtained from data on the second trip are lower than the rates obtained from data taken on the second trip to Elwood. This trend is not so easily noticed for the other categories of ambiguities.

On the second APL trip to Elwood, CDR-809 was made using real time video and CDR-812 was made from an FR-950 of the same video. The results obtained for these two tapes are much more in agreement than RUN 04A is with RUN 04B and RUN 04C, and CDR-807. The parameters causing the difference that results when FR-950 tapes are used have not been determined, but they should be.

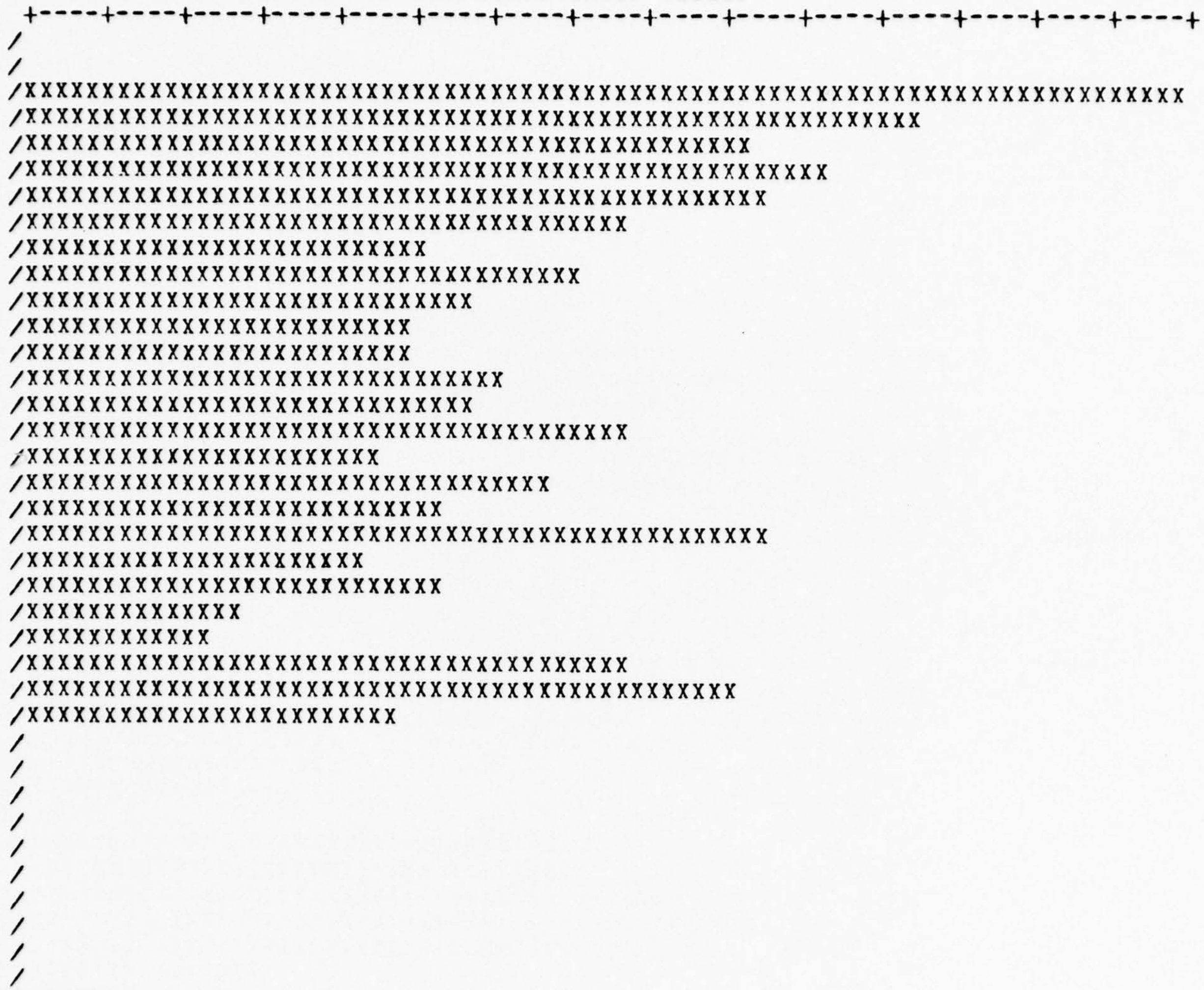
8.4.3.4 Effect of Mode Interlace

An experiment was done to determine the effect of beacon interrogator mode interlace on the ambiguity rates. On the second APL trip three runs were made using real time video, each with a different mode interlace selected. These runs are listed in Table 8.3. A comparison of the range split rates and sidelobe rates in Table 8.15 for the three tapes shows that the CDR-811, the tape made with the 3/A only interlace, also had the highest ambiguity rates of the three tapes in range split and sidelobe categories. Tape CDR-810, made with the lowest 3/A rate (interlace 3/A, C, 2), also had the lowest ambiguity rate in these categories. Tape CDR-809, made with the 3/A, 3/A, C interlace, was between the other two rates. The same trend is also noted for the mainbeam reflections, but these as well as azimuth splits are too rare to consider. The results support the theory that the beacon Mode 3/A replies are being divided among the reports generated. When more 3/A replies are available it is more likely that an extra, ambiguous report will be generated. Notice that the data for reflection rates does not exhibit the same trend, which is because these are not ambiguities being generated by the sharing of replies, but actually two or more targets each with its own associated replies. The incorrectly determined ambiguities are so flagged because they both are squawking the same discrete code.

8.4.3.5 Spatial Distributions (Range, Azimuth, Altitude)

For all the tapes analyzed, the ambiguity rates, normalized to one so that they may be interpreted as estimates of probability, were plotted as function of range, azimuth and altitude to determine if ambiguities tend to occur in specific areas. Figure 8.30 is the ambiguity rate of tape RUN 001 as a function of range. The analysis was done between 11 nmi and 188 nmi. The range of the first target report out of the CD which formed each ambiguity to make this plot. The general trend of the distribution is toward an increased ambiguity rate at the closer range. The rates were determined for ambiguities consisting of any number of reports. A similar plot was made for ambiguities consisting of two reports (pairs) only and was virtually the same in appearance. Figure 8.31 presents the ambiguity rate of RUN 002 as a function of range for all ambiguity group sizes. This one is presented because the trend of the plot is somewhat different than RUN 001. Here, the rate above about 55 nmi increases, with increasing range. Below this range, the rate, which is relatively small at the 57 nmi bin, becomes larger again. A similar plot was done of RUN 002 for pairs only and is shown in Figure 8.32. A comparison of Figure 8.31 with 8.32 reveals that the larger group sizes (non pairs) are responsible for the increasing ambiguity rate as a function of range in Figure 8.31 beyond 57 nmi. When these are removed, the ambiguity shows a steady trend to decrease with increasing range. Most of the data analyzed had range plots resembling that of Figure 8.30, though a great deal of variability was present. A number of factors can affect the rate at which ambiguities occur at a given range. For example, sidelobe ambiguities will tend to occur at lower ranges because the reduced antenna gain through the sidelobes requires that the signal from the target be stronger to achieve the same output from the receiver. Range splits were observed on the display to be isotropic. Detected reflections, which are usually two targets with the same discrete beacon code tend to occur at longer ranges. This is because the closer two aircraft fly together, the more likely it is that they are under control by the same air traffic control facility. When assigning discrete beacon codes to aircraft, a facility will only give one aircraft any particular discrete beacon code. In order that two or more aircraft have the same discrete beacon code, they must have been under the control of different ATC facilities. Consequently, the detected reflections will tend to be separated by large distance and therefore tend to be at the longer ranges.

AMBIGUITY RATE AS A FUNCTION OF RANGE(ALL GROUP SIZES)



RANGE (nm)	RATE
0.000	0.000
7.125	0.000
14.250	0.116
21.375	0.091
28.500	0.073
35.625	0.082
42.750	0.076
49.875	0.061
57.000	0.041
64.125	0.057
71.250	0.046
78.375	0.040
85.500	0.040
92.625	0.048
99.750	0.045
106.875	0.061
114.000	0.036
121.125	0.054
128.250	0.043
135.375	0.076
142.500	0.036
149.625	0.043
156.750	0.023
163.875	0.020
171.000	0.062
178.125	0.072
185.250	0.037
192.375	0.000
199.500	0.000
206.625	0.000
213.750	0.000
220.875	0.000
228.000	0.000
235.125	0.000
242.250	0.000
249.375	0.000
256.500	0.000

ENTRIES OUTSIDE OF TABLE: 0

FIGURE 8.30

AMBIGUITY RATE VS RANGE FOR TAPE RUN 001

AMBIGUITY RATE AS A FUNCTION OF RANGE(ALL GROUP SIZES)

RANGE (nm)	RATE
0.000	0.000
7.125	0.095
14.250	0.022
21.375	0.062
28.500	0.066
35.625	0.056
42.750	0.049
49.875	0.046
57.000	0.008
64.125	0.023
71.250	0.029
78.375	0.029
85.500	0.014
92.625	0.015
99.750	0.011
106.875	0.017
114.000	0.017
121.125	0.041
128.250	0.042
135.375	0.025
142.500	0.039
149.625	0.056
156.750	0.078
163.875	0.028
171.000	0.057
178.125	0.060
185.250	0.053
192.375	0.046
199.500	0.000
206.625	0.000
213.750	0.000
220.875	0.000
228.000	0.000
235.125	0.000
242.250	0.000
249.375	0.000
256.500	0.000

ENTRIES OUTSIDE OF TABLE: 0

FIGURE 8.31

AMBIGUITY RATE VS RANGE FOR RUN 002

```
                 AMBIGUITY RATE AS A FUNCTION OF RANGE(PAIRS ONLY)
RANGE (nm)      RATE    +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
  0.000         0.000   /
  7.125         0.076   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 14.250         0.022   /XXXXXXXXXXXXXXXXXXXX
 21.375         0.065   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 28.500         0.066   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 35.625         0.079   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 42.750         0.049   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 49.875         0.043   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 57.000         0.011   /XXXXXXXXXX
 64.125         0.044   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 71.250         0.032   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 78.375         0.030   /XXXXXXXXXXXXXXXXXXXXXXXXXXXX
 85.500         0.022   /XXXXXXXXXXXXXXXXXXXX
 92.625         0.044   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 99.750         0.030   /XXXXXXXXXXXXXXXXXXXXXXXXXXXX
106.875         0.027   /XXXXXXXXXXXXXXXXXXXXXXXXX
114.000         0.031   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
121.125         0.034   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
128.250         0.007   /XXXXXX
135.375         0.032   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
142.500         0.011   /XXXXXXXXXX
149.625         0.009   /XXXXXXXX
156.750         0.018   /XXXXXXXXXXXXXXXXX
163.875         0.000   /
171.000         0.000   /
178.125         0.009   /XXXXXXXX
185.250         0.018   /XXXXXXXXXXXXXXXX
192.375         0.000   /
199.500         0.000   /
206.625         0.000   /
213.750         0.000   /
220.875         0.000   /
228.000         0.000   /
235.125         0.000   /
242.250         0.000   /
249.375         0.000   /
256.500         0.000   /
ENTRIES OUTSIDE OF TABLE:       0
```

FIGURE 8.32

AMBIGUITY RATE (PAIRS ONLY) VS RANGE FOR TAPE RUN 002

Similar plots of ambiguity rate as a function of azimuth were developed. Figure 8.33 is a plot of this for RUN 001. The azimuth of each bin is determined by multiplying the corresponding number in the column labeled AZMUTH by 360°. In this plot, there is an azimuth sector of relatively high rates. It is interesting to look at the actual distribution of the frequency of occurrence of the ambiguities in azimuth shown in Figure 8.34. The sector of relatively few ambiguities in Figure 8.34 actually has an ambiguity rate that is higher as shown by Figure 8.33. Figure 8.22 is the azimuth distribution of the target reports themselves. The sector of lowest target report density corresponds to the sector of relatively few ambiguities which can be seen by comparing 8.22 with 8.34, but Figure 8.33 shows this to be an area of relatively high ambiguity rates. This phenomena is typical of all the data taken. The reason for this behavior is not known, but could probably be resolved by additional use of the display. The azimuth plots for pairs only are virtually the same.

Figure 8.35 is the ambiguity rate as a function of altitude (given in hundreds of feet) for tape RUN 001. No unusual characteristics can be observed. The distribution of ambiguities with altitude is judged to be uniform. The plot of ambiguity rates for pairs only as a function of altitude for this tape is essentially the same. The altitude characteristic for the other tapes were not considered significantly different.

In general it was observed that whenever targets were present, ambiguities occurred. The ambiguity rates are affected by many factors, and no features in the distributions show that ambiguities were significantly distributional. Additional study of these types of distributions is not considered worthwhile as this will probably reveal no new information concerning the causes or remedies for the ambiguities.

8.4.3.6 Distribution of Separations - Range and Azimuth

A characteristic of ambiguities is the separations, in range and azimuth, of the reports comprising each ambiguity. For each analysis listed in Table 8.12, distributions of the range separation and azimuth separation of the ambiguities were developed. For non pairs this was done by plotting a normalized histogram of the maximum range separations and a histogram of maximum azimuth separation occurring between reports forming each ambiguity. In the case of the azimuth separations for pairs, the report with the lower range is chosen as the reference and the azimuth separation of the other report is measured from this reference, leading to both positive and negative separations. For non pairs, only absolute values of azimuth separation are plotted. Range separation was always an absolute value.

```
          AMBIGUITY RATE AS A FUNCTION OF AZIMUTH(ALL GROUP SIZES)
AZMUTH* RATE     +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
0.000    0.057 /XXXXXXXXXXXXXXXXXXXX
0.028    0.049 /XXXXXXXXXXXXXXXXX
0.056    0.057 /XXXXXXXXXXXXXXXXXXXX
0.083    0.052 /XXXXXXXXXXXXXXXXXX
0.111    0.055 /XXXXXXXXXXXXXXXXXXX
0.139    0.034 /XXXXXXXXXXX
0.167    0.042 /XXXXXXXXXXXXXX
0.195    0.030 /XXXXXXXXXX
0.222    0.093 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.250    0.078 /XXXXXXXXXXXXXXXXXXXXXXXXXXX
0.278    0.039 /XXXXXXXXXXXXX
0.306    0.088 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.334    0.122 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.361    0.112 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.389    0.115 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.417    0.043 /XXXXXXXXXXXXXXX
0.445    0.156 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.473    0.140 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.500    0.211 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.528    0.134 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.556    0.126 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.584    0.205 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.612    0.038 /XXXXXXXXXXXXX
0.639    0.045 /XXXXXXXXXXXXXXX
0.667    0.048 /XXXXXXXXXXXXXXXX
0.695    0.047 /XXXXXXXXXXXXXXXX
0.723    0.026 /XXXXXXXXX
0.751    0.042 /XXXXXXXXXXXXXX
0.778    0.034 /XXXXXXXXXXX
0.806    0.034 /XXXXXXXXXXX
0.834    0.036 /XXXXXXXXXXXX
0.862    0.052 /XXXXXXXXXXXXXXXXXX
0.890    0.054 /XXXXXXXXXXXXXXXXXXX
0.917    0.031 /XXXXXXXXXXX
0.945    0.048 /XXXXXXXXXXXXXXXXX
0.973    0.031 /XXXXXXXXXXX
1.001    0.069 /XXXXXXXXXXXXXXXXXXXXXXXX
ENTRIES OUTSIDE OF TABLE:      0
```

*Azimuth: Multiply by 360 to obtain azimuth in degrees
Multiply by 2π to obtain azimuth in radians
Multiply by 4096 to obtain azimuth in ACP's

FIGURE 8.33

AMBIGUITY RATE VS AZIMUTH FOR TAPE RUN 001

```
      AMBIGUITY AZIMUTH POSITION DISTRIBUTION(ALL GROUP SIZES)
AZMUTH* PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
0.000    0.020 /XXXXXXXXXXXXX
0.028    0.035 /XXXXXXXXXXXXXXXXXXXXXXX
0.056    0.048 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.083    0.053 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.111    0.056 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.139    0.015 /XXXXXXXXX
0.167    0.023 /XXXXXXXXXXXXXXX
0.195    0.015 /XXXXXXXXX
0.222    0.022 /XXXXXXXXXXXXXX
0.250    0.013 /XXXXXXXX
0.278    0.006 /XXX
0.306    0.007 /XXXX
0.334    0.006 /XXX
0.361    0.006 /XXX
0.389    0.004 /XX
0.417    0.003 /X
0.445    0.015 /XXXXXXXXX
0.473    0.019 /XXXXXXXXXXXX
0.500    0.018 /XXXXXXXXXXX
0.528    0.012 /XXXXXXX
0.556    0.064 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.584    0.113 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.612    0.019 /XXXXXXXXXXXX
0.639    0.042 /XXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.667    0.029 /XXXXXXXXXXXXXXXXXXX
0.695    0.037 /XXXXXXXXXXXXXXXXXXXXXXXX
0.723    0.012 /XXXXXXX
0.751    0.023 /XXXXXXXXXXXXXXX
0.778    0.026 /XXXXXXXXXXXXXXXXX
0.806    0.028 /XXXXXXXXXXXXXXXXXX
0.834    0.048 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.862    0.056 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.890    0.029 /XXXXXXXXXXXXXXXXXXX
0.917    0.012 /XXXXXXX
0.945    0.022 /XXXXXXXXXXXXXX
0.973    0.022 /XXXXXXXXXXXXXX
1.001    0.022 /XXXXXXXXXXXXXX
ENTRIES OUTSIDE OF TABLE:     0
```

*Azimuth: Multiply by 360 to obtain azimuth in degrees
Multiply by 2π to obtain azimuth in radians
Multiply by 4096 to obtain azimuth in ACP's

FIGURE 8.34

AMBIGUITY AZIMUTH DISTRIBUTION FOR TAPE RUN 001

AMBIGUITY RATE AS A FUNCTION OF ALTITUDE(ALL GROUP SIZES)

ALTITUDE*	RATE
0.	0.032
14.	0.054
28.	0.066
42.	0.044
56.	0.038
70.	0.033
84.	0.039
98.	0.088
112.	0.065
126.	0.074
140.	0.039
154.	0.063
168.	0.062
182.	0.110
196.	0.030
210.	0.056
224.	0.053
238.	0.068
252.	0.059
266.	0.055
280.	0.032
294.	0.057
308.	0.049
322.	0.026
336.	0.088
350.	0.098
364.	0.000
378.	0.022
392.	0.061
406.	0.000
420.	0.000
434.	0.000
448.	0.000
462.	0.000
476.	0.000
490.	0.000
504.	0.000

ENTRIES OUTSIDE OF TABLE: 0

*Altitude: (hundreds of feet)

FIGURE 8.35

AMBIGUITY RATE VS ALTITUDE FOR TAPE RUN 001

Figure 8.36 is the distribution of range separation for the non pairs of tape RUN 001. The majority of the separations are below 3.5 nmi in range. A check with Table 8.18 shows that three percent of the ambiguities of this tape are non pairs consisting of range splits, sidelobes, and reflections. Sidelobes of the non pair type will include ring around problems if they are present. The range splits and sidelobes which are non pairs will, of course, contribute only to this bin (the 0 bin which includes separations between 0 and 3.5 nmi) because of the requirement that the range separations in these categories be less than or equal to 1/4 nmi. From Table 8.13 it can be computed that non pair range splits and non pair sidelobes account for 65 percent of the 20 non pair ambiguities meaning that one detected reflection is contributing to this bin which contains, from Figure 8.36, 70 percent of the non pairs. The remaining 30 percent at the larger range separations are all detected reflections. All of the range separation distributions for non pairs for the other tapes have the same characteristics, because sidelobes and range splits have small range separations while mainbeam relfections and reflections have larger separations. There were no non pair azimuth splits pbserved. Figure 8.37 is the range separation for pairs only for RUN 001. The characteristics of this distribution are similar to those of the non pair distribution. Most of the ambiguities are separated by small ranges. This is easily explained by the fact that sidelobes and range splits were the major ambiguities for this tape. Next were reflections, azimuth splits, and mainbeam reflection, the latter two of which were very rare. What is being observed are the close separation of the sidelobes and range splits in the first bin, and primarily reflections in the other, larger separation bins. Similar characteristics are exhibited for the other analyses done as well. The range separations are reflecting the relative mix of ambiguity types.

Figure 8.38 is the histogram of azimuth separation for non pairs of RUN 001. The bin labeled 5 covers from 2.5 to 7.5° in azimuth and includes all the non pair range splits, and would also include all the mainbeam reflections, had any non pairs occurred for this run. The other classes of ambiguities may occur in this bin as well as larger azimuth separations as well. Similar logic applies to the non pair azimuth distributions for the other runs as well. Figure 8.39 is the azimuth separation for the ambiguity pairs detected on RUN 001. For the pairs, azimuth separation between 0° and ±5° dominate. These are primarily range splits. Between ±5° and ±15° are where most of the sidelobes occur. The larger separations are mostly reflections. Similar results are observed for the other analyses done.

In general, both the range and azimuth separation distributions reflect the mixture of target report ambiguity types that were detected. Range splits tend to dominate, followed by sidelobes and reflections. The other types of ambiguities are quite rare, as observed from Table 8.15.

```
NON PAIR MAXIMUM RANGE SEPARATION HISTOGRAM
RANGE(nm)  PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
  0.000    0.700   /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  7.000    0.000   /
 14.000    0.000   /
 21.000    0.000   /
 28.000    0.000   /
 35.000    0.000   /
 42.000    0.000   /
 49.000    0.200   /XXXXXXXXXXXXXXXXXXXX
 56.000    0.050   /XXXXX
 63.000    0.000   /
 70.000    0.000   /
 77.000    0.050   /XXXXX
 84.000    0.000   /
 91.000    0.000   /
 98.000    0.000   /
105.000    0.000   /
112.000    0.000   /
119.000    0.000   /
126.000    0.000   /
133.000    0.000   /
140.000    0.000   /
147.000    0.000   /
154.000    0.000   /
161.000    0.000   /
168.000    0.000   /
175.000    0.000   /
182.000    0.000   /
189.000    0.000   /
196.000    0.000   /
203.000    0.000   /
210.000    0.000   /
217.000    0.000   /
224.000    0.000   /
231.000    0.000   /
238.000    0.000   /
245.000    0.000   /
252.000    0.000   /
ENTRIES OUTSIDE OF TABLE:      0
```

FIGURE 8.36

NORMALIZED HISTOGRAM OF RANGE SEPARATIONS FOR NON PAIR AMBIGUITIES FOR RUN 001

```
                         RANGE SEPERATION DISTRIBUTION
RANGE(nm)     PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
   0.000       0.817  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   7.000       0.014  /X
  14.000       0.012  /X
  21.000       0.014  /X
  28.000       0.008  /
  35.000       0.003  /
  42.000       0.014  /X
  49.000       0.062  /XXXXX
  56.000       0.023  /XX
  63.000       0.003  /
  70.000       0.000  /
  77.000       0.018  /X
  84.000       0.000  /
  91.000       0.003  /
  98.000       0.001  /
 105.000       0.000  /
 112.000       0.000  /
 119.000       0.001  /
 126.000       0.000  /
 133.000       0.001  /
 140.000       0.005  /
 147.000       0.000  /
 154.000       0.000  /
 161.000       0.001  /
 168.000       0.000  /
 175.000       0.000  /
 182.000       0.000  /
 189.000       0.000  /
 196.000       0.000  /
 203.000       0.000  /
 210.000       0.000  /
 217.000       0.000  /
 224.000       0.000  /
 231.000       0.000  /
 238.000       0.000  /
 245.000       0.000  /
 252.000       0.000  /
ENTRIES OUTSIDE OF TABLE:      0
```

FIGURE 8.37

NORMALIZED HISTOGRAM OF RANGE SEPARATION OF AMBIGUITY PAIRS FOR RUN 001

```
    NON PAIR MAXIMUM AZIMUTH SEPARATION HISTOGRAM
  AZMUTH*  PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
   0.000    0.000 /
   5.000    0.100 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  10.000    0.050 /XXXXXXXXXXXXXX
  15.000    0.050 /XXXXXXXXXXXXXX
  20.000    0.250 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  25.000    0.100 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  30.000    0.000 /
  35.000    0.050 /XXXXXXXXXXXXXX
  40.000    0.000 /
  45.000    0.050 /XXXXXXXXXXXXXX
  50.000    0.000 /
  55.000    0.000 /
  60.000    0.000 /
  65.000    0.000 /
  70.000    0.000 /
  75.000    0.000 /
  80.000    0.000 /
  85.000    0.050 /XXXXXXXXXXXXXX
  90.000    0.150 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  95.000    0.000 /
 100.000    0.100 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 105.000    0.000 /
 110.000    0.000 /
 115.000    0.000 /
 120.000    0.050 /XXXXXXXXXXXXXX
 125.000    0.000 /
 130.000    0.000 /
 135.000    0.000 /
 140.000    0.000 /
 145.000    0.000 /
 150.000    0.000 /
 155.000    0.000 /
 160.000    0.000 /
 165.000    0.000 /
 170.000    0.000 /
 175.000    0.000 /
 180.000    0.000 /
ENTRIES OUTSIDE OF TABLE:      0
```

*AZIMUTH SEPARATION IN DEGREES

FIGURE 8.38

NORMALIZED HISTOGRAM OF AZIMUTH SEPARATION OF NON PAIR AMBIGUITIES FOR RUN 001

```
                         AZIMUTH SEPARATION OF PAIRS
 AZMUTH* PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
-180.000   0.000 /
-170.000   0.000 /
-160.000   0.000 /
-150.000   0.000 /
-140.000   0.000 /
-130.000   0.001 /
-120.000   0.000 /
-110.000   0.000 /
-100.000   0.005 /
-90.000   0.001 /
-80.000   0.000 /
-70.000   0.000 /
-60.000   0.001 /
-50.000   0.003 /
-40.000   0.014 /X
-30.000   0.011 /X
-20.000   0.008 /
-10.000   0.060 /XXXXXX
  0.000   0.715 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 10.000   0.033 /XXX
 20.000   0.005 /
 30.000   0.006 /
 40.000   0.001 /
 50.000   0.001 /
 60.000   0.000 /
 70.000   0.001 /
 80.000   0.001 /
 90.000   0.075 /XXXXXXX
100.000   0.039 /XXXX
110.000   0.001 /                                   *AZIMUTH SEPARATION IN DEGREES
120.000   0.001 /
130.000   0.000 /
140.000   0.005 /
150.000   0.001 /
160.000   0.005 /
170.000   0.003 /
180.000   0.000 /
ENTRIES OUTSIDE OF TABLE:      0
```

FIGURE 8.39

NORMALIZED HISTOGRAM OF AZIMUTH SEPARATION OF AMBIGUITY PAIRS FOR RUN 001

8.4.3.7 Range Splits

Range splits were found, in all the analyses done, to be a very significant contribution to the ambiguity problem. In addition, range splits and possibly mainbeam reflections are thought to be direct consequence of CD processing as opposed to sidelobes and reflections which, although they may be solved by CD processing, are caused by antenna and siting problems. Range splits were given some additional attention because their suspected cause is related directly to CD processing. A duplicate discrete code analysis was done for each tape over essentially the same intervals given in Table 8.12 with the allowed range separation between .125 and 1.00 nmi and up to 10° in azimuth. With this window, the detected ambiguities were almost exclusively range splits. Table 8.19 presents the results. For this analysis, the ambiguities were not categorized into the five classes. Instead, it was assumed that range splits were normally very close in range and azimuth separations. The purpose of the analysis was to determine just how close they usually are. The approach was to allow a separation window a little larger than the expected maximum separations for range splits, then observe the resulting data. The percent of detected range splits for each run given in Table 8.19 compares favorably with those given in Table 8.15 where the overall breakdown of splits was listed. Included in the range split analysis is the number of detected ambiguities separated by exactly 0.125 nmi in range, which is the range separation which is almost always observed for range splits. The percentages aretabulated in Table 8.19. Also, an adjusted range split rate based only on those ambiguities separated by 0.125 nmi is listed in Table 8.14. These values compare even more favorably to the range split rates given in Table 8.15. The differences are because different sizes were used and a few of the range splits in the second analysis may have been other types of ambiguities in the first analysis as a result.

Further, Table 8.19 tabulates the percentage of ambiguities that were pairs, and also other group sizes up to five. Of these pairs, the azimuth separation for which 95% of the ambiguities do not exceed was computed from the azimuth separation distributions for pairs and listed. Notice that almost all were three degrees or less. Tape RUN 006 exceeded this and was at 4.17°, but 89% were less than 3.9° for this tape. An unusual azimuth separation distribution explains this and will be discussed shortly.

For tape CDR-805, the minimum azimuth separation including 95% of the pairs was 9.2° but 81% were within 2°. Recall that CDR-805, however, was found to have been made from an unknown video source, and therefore conclusions based on this tape should not be made. At any rate, the conclusions to be made from this table are that most of the detected ambiguities were pairs separated by 3° or less in azimuth and 0.125 nmi in azimuth. These are the features of range splits.

TABLE 8.19

RESULTS OF DATA COLLECTED FOR DETERMINING RANGE SPLIT CHARACTERISTICS
(See Section 8.4.3.7 for Proper Interpretation of Data in this Table)

Separation Criteria for Analysis:

ΔR = 0.125 to 1.000 nmi

$\Delta\theta$ = 0 to 10°

CD-RECORD TAPE	ANALYSIS TIMES		ANALYSIS RANGE		DISCRETE REPORTS	DETECTED AMBI-GUITIES	PERCENT AMBIGUITIES	PERCENT OF AMBIGUITIES WITH CERTAIN GROUP SIZE				AZ SEP FOR 95% OF PAIRS LESS THAN		% PAIRS SEPARATED BY .125 NMI	SPLIT RATE PAIRS ONLY SEP BY .125
	START	STOP	LOWER BOUND	UPPER BOUND				GROUP SIZE 2	3	4	5	DEG	ACP's		
RUN 001	9:51:01	10:11:01	11	188	12303	484	3.93	100	0	0	0	2.50	28.4	96.7	3.80
RUN 002	10:58:01	11:16:01	0	256	9400	142	1.51	100	0	0	0	2.50	28.4	98.6	1.49
RUN 003	13:08:00	13:28:00	0	256	5471	189	3.45	100	0	0	0	1.94	22.1	97.4	3.36
RUN 04A	13:34:00	14:47:21	11	188	10008	436	4.36	99.8	.2	0	0	1.94	22.1	96.3	4.19
RUN 04B	15:18:56	15:32:17	11	188	9462	299	3.16	100	0	0	0	2.50	28.4	96.0	3.03
RUN 04C	15:42:39	15:56:00	11	188	11003	349	3.17	99.7	0.3	0	0	3.06	34.8	92.8	2.94
RUN 005	10:12:24	10:26:24	11	245	2051	37	1.80	100	0	0	0	1.94	22.1	100.00	1.80
RUN 006	11:18:00	11:39:00	0	256	3144	72	2.29	100	0	0	0	4.17	47.4[1]	100.00	2.29
CDR-803	13:34:39	13:54:39	11	245	1969	23	1.17	100	0	0	0	1.39	15.8	100.00	1.17
CDR-804	14:33:21	14:53:21	11	188	10082	244	2.42	100	0	0	0	3.61	41.1	97.5	2.36
CDR-805	15:06:57	15:24:57	0	256	9347	164	1.75	100	0	0	0	9.17	10.4[2]	95.7	1.68
CDR-807	9:41:21	9:54:42	11	188	7135	125	1.75	100	0	0	0	2.5	28.4	96.8	1.70
CDR-809	10:54:00	11:14:00	11	210	15839	227	1.43	100	0	0	0	2.5	28.4	94.7	1.36
CDR-810	11:23:00	11:43:00	11	210	9127	25	0.274	100	0	0	0	3.1	34.8	96.0	0.263
CDR-811	13:00:00	13:15:00	11	210	7741	126	1.63	100	0	0	0	2.5	28.4	96.8	1.58

1. 88.9% inside 2.5° (28.4 ACP's) see text
2. 91% inside 1.94° (22.1 ACP's) see text

Figure 8.40 is the range separation distribution as produced by the range split analysis for RUN 001. Range in the CD is reported with a resolution of 1/8 nmi, so that the bins of this separation histogram correspond exactly to the increments at which separation can be computed. In this case, almost 97 percent were reported by 0.125, almost 3° by 0.250, and the remainder by larger amounts. Practically, all the detected ambiguities were within 1/4 nmi with most within 1/8 nmi. Range cells in the CD are 1/4 nmi, so that nearly all the range splits detected by this analysis were in adjacent range cells (i.e. neither 1/8 nmi or 1/4 nmi separation).

Figure 8.41 is the distribution of azimuth separations for RUN 001. Obviously, most were less than three degrees. Furthermore, the closer azimuth separations occur more frequently, with the 0° bin (±.278°) having the highest probability. These range and azimuth separation plots are characteristic of the analyses done. The azimuth distribution for RUN 006 had a peculiar glitch in it that is worthy of pointing out. Figure 8.42 is the distribution of azimuth separation for RUN 006. The characteristic distribution confining itself to less then ±3° is present but to the left, and between about 4 and 5°, another group of ambiguities exist. These may be sidelobe ambiguities. It was determined that these ambiguities occur uniformly through the duration of the tape but no additional analysis was done. Figure 8.4.2 is a typical distribution and was observed for RUN 006 only.

This section presented evidence that range splits are separated by less then 3° in azimuth and lie in adjacent range cells usually reported by a 1/8 nmi but sometimes by a 1/4 nmi. The azimuth distribution shows that the most favored separation in azimuth is 0°. Recall that the proposed mechanism for the generation of range splits is the random jumping of transponder replies from an aircraft between two adjacent cells such that each cell received a quantity of replies sufficient to declare a target report leading edge.

It should be realized that another, reasonable sounding explanation might be that the target simply crossed the range cell boundary during the mainbeam scan past it, thereby putting replies first in one range cell, then in the adjacent cell. If this were the case, however, the azimuth separation distribution would favor some non zero separation because the antenna mainbeam would be sweeping through different azimuths for the adjacent range cell than the original range cell. What the observed azimuth separation distribution says is that both reports tend to be formed from replies simultaneously, which is evidence supporting the range jitter theory.

```
                           AMBIGUITY SEPERATION DISTRIBUTION
RANGE(nm)  PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
0.125      0.967  /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
0.250      0.027  /XX
0.375      0.000  /
0.500      0.002  /
0.625      0.004  /
0.750      0.000  /
0.875      0.000  /
1.000      0.000  /
1.125      0.000  /
1.250      0.000  /
1.375      0.000  /
1.500      0.000  /
1.625      0.000  /
1.750      0.000  /
1.875      0.000  /
2.000      0.000  /
2.125      0.000  /
2.250      0.000  /
2.375      0.000  /
2.500      0.000  /
2.625      0.000  /
2.750      0.000  /
2.875      0.000  /
3.000      0.000  /
3.125      0.000  /
3.250      0.000  /
3.375      0.000  /
3.500      0.000  /
3.625      0.000  /
3.750      0.000  /
3.875      0.000  /
4.000      0.000  /
4.125      0.000  /
4.250      0.000  /
4.375      0.000  /
4.500      0.000  /
4.625      0.000  /
```

FIGURE 8.40

NORMALIZED HISTOGRAM OF RANGE SEPARATION OF PAIRS FOR RUN 001 - ANALYSIS OF TABLE 8.19

```
                       AZIMUTH SEPARATION OF PAIRS
AZMUTH* PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
-9.998   0.000 /
-9.442   0.000 /
-8.887   0.000 /
-8.331   0.000 /
-7.776   0.000 /
-7.220   0.000 /
-6.665   0.000 /
-6.110   0.000 /
-5.554   0.000 /
-4.999   0.004 /X
-4.443   0.000 /
-3.888   0.000 /
-3.333   0.004 /X
-2.777   0.004 /X
-2.222   0.033 /XXXXXXXXXX
-1.666   0.081 /XXXXXXXXXXXXXXXXXXXXXXXX
-1.111   0.099 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-0.555   0.188 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 0.000   0.244 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 0.555   0.116 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.111   0.093 /XXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.666   0.078 /XXXXXXXXXXXXXXXXXXXXXXXX
 2.222   0.025 /XXXXXXX
 2.777   0.012 /XXX
 3.333   0.002 /
 3.888   0.002 /
 4.443   0.000 /
 4.999   0.002 /
 5.554   0.002 /
 6.110   0.002 /
 6.665   0.000 /
 7.220   0.000 /
 7.776   0.000 /
 8.331   0.000 /
 8.887   0.002 /
 9.442   0.006 /X
 9.998   0.000 /
```

*AZIMUTH SEPARATION IN DEGREES

FIGURE 8.41

NORMALIZED HISTOGRAM OF AZIMUTH SEPARATION OF PAIRS FOR RUN 001 - ANALYSIS OF TABLE 8.19

```
                       AZIMUTH SEPARATION OF PAIRS
AZMUTH* PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
-9.998   0.000 /
-9.442   0.000 /
-8.887   0.000 /
-8.331   0.000 /
-7.776   0.000 /
-7.220   0.000 /
-6.665   0.000 /
-6.110   0.000 /
-5.554   0.000 /
-4.999   0.014 /XXXX
-4.443   0.028 /XXXXXXXXX
-3.888   0.042 /XXXXXXXXXXXXXX
-3.333   0.000 /
-2.777   0.014 /XXXX
-2.222   0.014 /XXXX
-1.666   0.083 /XXXXXXXXXXXXXXXXXXXXXXXXXXXX
-1.111   0.139 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
-0.555   0.222 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 0.000   0.181 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 0.555   0.042 /XXXXXXXXXXXXXX
 1.111   0.097 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 1.666   0.097 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 2.222   0.014 /XXXX
 2.777   0.000 /
 3.333   0.000 /
 3.888   0.000 /
 4.443   0.000 /
 4.999   0.000 /
 5.554   0.000 /
 6.110   0.000 /
 6.665   0.014 /XXXX
 7.220   0.000 /
 7.776   0.000 /
 8.331   0.000 /
 8.887   0.000 /
 9.442   0.000 /
 9.998   0.000 /
```

*AZIMUTH SEPARATION IN DEGREES

FIGURE 8.42

NORMALIZED HISTOGRAM OF AZIMUTH SEPARATION OF PAIRS FOR RUN 006 - ANALYSIS OF TABLE 8.19

8.4.3.8 Sidelobes and the NADIF Modification

As indicated before, the inital approach to the ambiguity analysis was to use the display for a visual analysis of the target report data, with the TRAAP program used to detect the ambiguities. During the analysis of CDR-809, it was noticed that severe sidelobe problems were occurring at close ranges. Tape CDR-809 was made from real time video on the second APL trip to Elwood, while RUN 04A was made in real time on the first APL trip. RUN 04A was rechecked and found not to exhibit this severe problem. Figure 8.43 present three minutes of report data from RUN 04A. The ambiguities are in red and ordinary reports are green. Notice the number of ambiguities occurring at the center of the display. This display was expanded as shown in Figure 8.44 about the center for a more detailed examination. Very few red dots are present. Figure 8.45 presents three minutes of data from CDR-809. Notice that a cluster of red dots appears at the center of this display. This display was also expanded for a closer examination, shown in Figure 8.46. The phenomena clearly appears to be one of sidelobe returns. Several scans of data are displayed in Figure 8.46 making it difficult to tell exactly what is going on. A selected scan from the three minute interval of Figure 8.46 was displayed and is shown in Figure 8.47. Each red dot was hooked with ball tab and target report information was examined. The eight red reports in the western half of the display were found to be part of the same ambiguity, while the two red reports to the southeast were a different group. The eight ambiguous target reports are listed in Figure 8.47. One of the eight, at 12.625 nmi and 306°, was found to have a different code and no altitude. It is actually part of a different ambiguity which, by coincidence, turned up at this range so that it looks like part of the sidelobe problem. One of the important features of the sidelobe ambiguity group is that the report range changed during the generation of the ambiguity. The aircraft flight path was later examined, where it was verified that the airplane had an outbound radial velocity, resulting in the observed increase in range between the replies at 286° and 303° in Figure 8.47.

Other aircraft flying close to the sensor on tape CDR-809 also generated the severe sidelobe ambiguities, indicating sensor problems rather than transponder problems. The other tapes made in real time on the second APL trip also exhibited similar sidelobe problems. The overall sidelobe rate was not increased significantly because each group counts as only one sidelobe, regardless of how many reports are forming it. Most of the sidelobes are occurring at longer range and in pairs. However, the sidelobe problems such as those illustrated by Figure 8.45 through 8.47 which are approaching ring around, are significant for aircraft close to the sensor. It was determined that the NADIF antenna modification had been installed after the first APL trip to Elwood and prior to the second trip. The modification

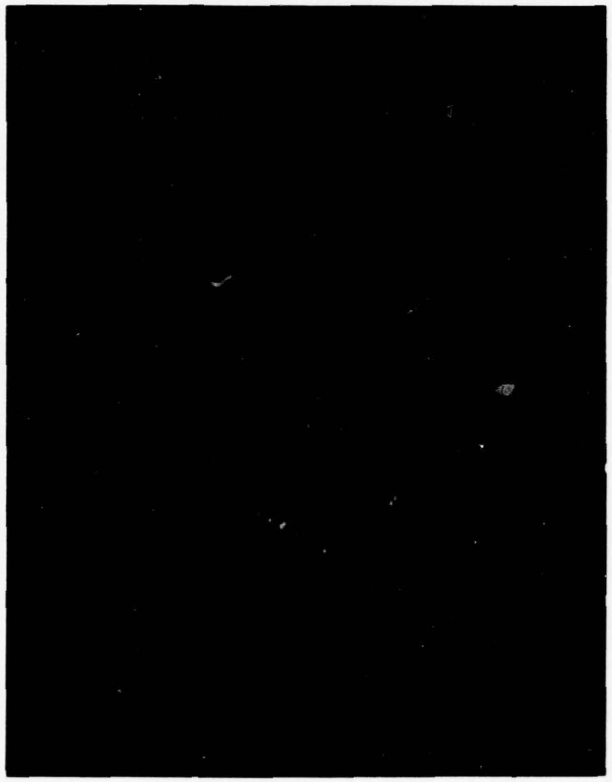
FIGURE 8.43

REPORT DATA FROM RUN 04A

* RUN 04A (REAL TIME, NAFEC, FEBRUARY 20)
* PRE–NADIF MOD
* 3 MIN OF DATA (14:34 $\longrightarrow$ 14:37)
* 75 NMI RINGS
* REPORTS IN GREEN DOTS
* AMBIGUITIES IN RED DOTS
* $\Delta R = 256$ NMI
* $\Delta\theta = 180°$
* DUPLICATE DISCRETE CODES

FIGURE 8.44

EXPANDED DISPLAY OF RUN 04A (CD–RECORD)



* 3 MIN DATA
* 5 NMI RINGS
* REPORTS IN GREEN
* AMBIGUITIES IN RED
* $\Delta R = 256$
* $\Delta \theta = 180^\circ$
* DUPLICATE DISCRETE CODE

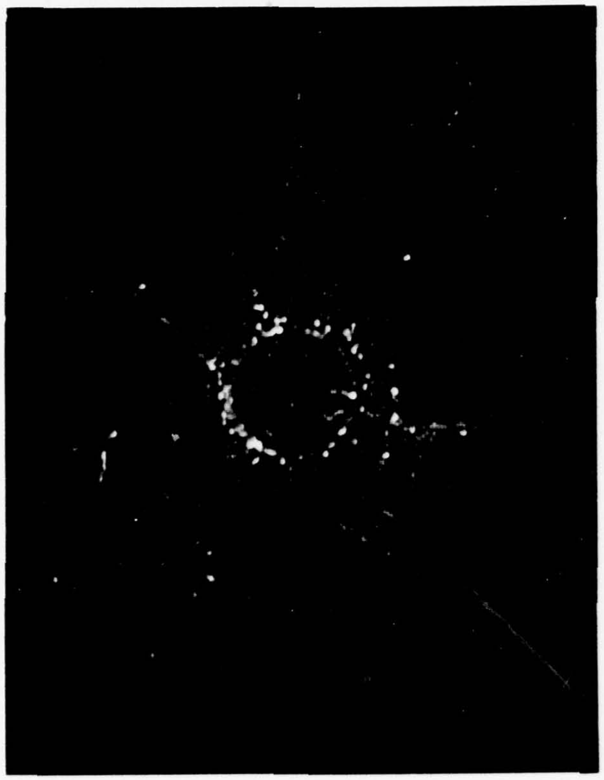
FIGURE 8.45

3 MIN OF CDR–809 (CD–RECORD)

* 10:52:00 ⟶ 10:55:00
* AFTER NADIF MOD
* 75 NMI RING
* REPORTS IN GREEN
* AMBIGUITIES IN RED
* $\Delta R = 256$ NMI
* $\Delta\theta = 180°$
* DUPLICATE DISCRETE CODES

FIGURE 8.46

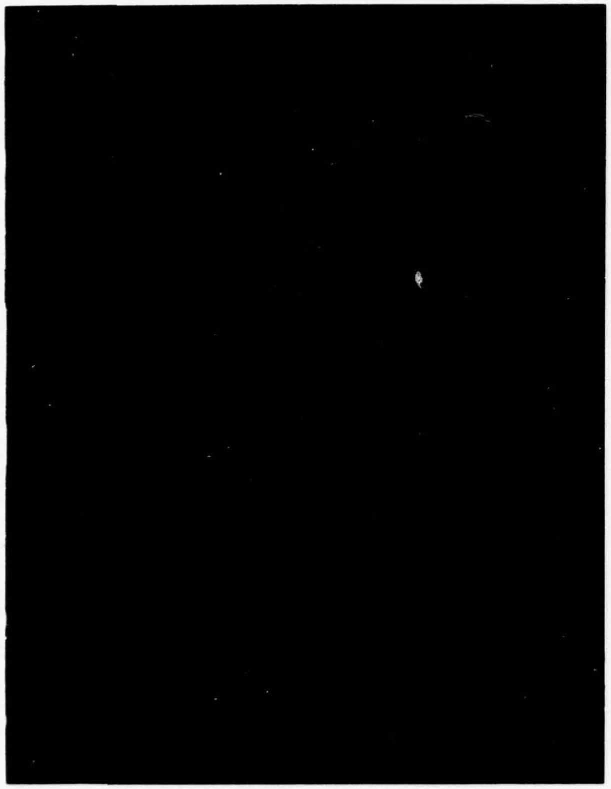
CDR—809 — EXPANDED DISPLAY (CD—RECORD)



* 10:52:00 ⟶ 10:55:00
* 5 NMI RING
* REPORTS IN GREEN
* *AMBIGUITIES IN RED*
* ΔR = 256 NMI
* $\Delta\theta$ = 180°
* DUPLICATE DISCRETE CODES

FIGURE 8.47

APPROXIMATELY ONE SCAN OF CDR–809 (CD–RECORD)



* 5 NMI RINGS
* REPORTS IN GREEN
* AMBIGUITIES IN RED
* $\Delta R = 256$ NMI, $\Delta\theta = 180^\circ$, D.D.C

LIST OF RED REPORT DATA

R	θ	CODE	ALT
12.500	209	2226	9100
12.500	248	2226	9100
12.500	258	2226	9100
12.500	286	2226	9100
12.625	303	2226	9100
12.625	306	3327	NONE
12.625	311	2226	9100
12.625	331	2226	9100

disables the so-called hog trough antenna and instead, a feed horn is mounted on the search radar antenna, which is then used as the beacon interrogator antenna. Some known problems existed with RF spillover from the feed horn around the antenna which then reflected off the antenna pedestal causing severe backlobe problems when the NADIF mod was first installed at other sites. Baffles have been used to correct this problem and have apparently reduced the problem at other sites. Evidently, the NADIF mode at Elwood was in need of further adjustment. Based on this single instance, it is not reasonable to draw a steadfast conclusion about the NADIF mod, which was originally designed as a fix for one particular site problem and is now being installed at all sites, If, however, the adjustment to eliminate these severe sidelobe problems is critical, the NADIF mod may do more harm than good.

8.4.4 Analysis of Radar-Beacon Misalignments

Radar-beacon misalignment refers to the failure of the CD to correlate corresponding radar and beacon returns from the same target to produce a single beacon target report which is distinguished as "radar reinforced." A measure of the effectiveness of this correlation is the radar reinforcement rate, which is the fraction of all beacon reports that are radar reinforced. Section 8.1.2 describes the beacon processing of the CD and, in particular, discusses the use of sliding window integration for target detection and centroiding. A very similar method is used for search radar data processing, except that the search sliding window length is different and a few other factors exist that are not significant to this discussion. A radar-beacon correlation is effected whenever an in-process target report has reached the target leading edge threshold in both the search and beacon sliding windows. This leading edge threshold need not be reached simultaneously by both windows. It is simply required that while the target report is in process for a given range cell, the leading edge threshold is reached by both the search and beacon sliding windows for that range cell. A target report will be in-process when either sliding window reaches its respective leading edge threshold. Once in process, the report will remain in process until the trailing edge threshold is reached for each sliding window that declared a leading edge threshold during the in-process time. Thus, in the case for a radar only or beacon only report, only the respective sliding window must read trailing edge to complete the target report (terminal in-process status). However, if both sliding windows declare a leading edge during the in-process time, both must declare a trailing edge before the in-process status is terminated. Whenever both sliding windows declare a target leading edge, the target report will be called a beacon report, radar reinforced. The centroiding will be based on the beacon sliding window.

When the CD receives both radar returns and beacon returns from a target but fails to correlate them, a radar report and a beacon report both are outputted.

For analysis of the radar-beacon misalignments, it was assumed that the failure to correlate the radar data and beacon data is a result of either a range or azimuth misalignment between the radar and beacon processing in the CD. In other words, for a given target the radar returns are coming in at a different range and/or azimuth than the beacon returns. If the radar returns and corresponding beacon returns end up in different range cells, correlation does not take place. Likewise, if the radar and beacon antennas were misaligned in azimuth, the radar and beacon sliding window would declare target report leading edges at substantially different times and correlation would be prevented. In fact, no azimuth misalignment of such magnitude exists. Also, both beacon and radar sliding windows for each sweep are processed before the next sweep. Since target detection is accomplished by azimuth integration over several sweeps, a large azimuth displacement would be

needed to prevent correlation. The failure to correlate radar and beacon return is, therefore, a result of a range misalignment. Statistics were accumulated by looking at each beacon target report that was not radar reinforced and searching a small area around it for the occurrence of a radar report. When such a report was found, it was called a misalignment, and histogram data on the range separation and azimuth separation of the radar report from the beacon report was accumulated. In addition, for each misalignment, radar reinforcement rate and misalignment rate were computed. In all cases the statistical accumulation was done only over regions where heavy radar clutter was not present and both radar and beacon processing were in effect.

In much of the data collected, there was an offset in range between the radar and beacon processing. For example, certain modifications to the CD were installed after some of the FR-950 video recordings were made. When the FR-950 tapes were played back through the modified CD, there was a constant offset between the radar and beacon processing. In other cases, a constant offset was deliberately inserted. The effect of the offset, naturally, is to reduce the radar reinforcement rate to a very low value. Whenever both radar returns and beacon returns were received from a target, the offset prevented correlation resulting in a radar report and a beacon report for that target. With both reports present, it was possible to accumulate histograms data for the range separation accurate to 1/8 nmi and histogram data for the azimuth separation. This is not possible for those targets that are reinforced. As described before, the correlation takes place any time that a radar and beacon leading edge are both declared for an in-process target in the same range cell. When this happens a single report is generated and the centroiding and range are obtained from the beacon data. As a consequence, azimuth data for the radar returns is lost. Furthermore, range cells are 1/4 nmi in length but range is reported accurate to 1/8 nmi. This resolution within the range cell is also lost for the radar data when a correlation is made. For purposes of collecting data to describe the range and azimuth variations between radar and beacon data, it is therefore a decided advantage to have a constant offset that prevents radar-beacon correlation. The known offsets are listed in the data Section 8.2.

8.4.4.1 Results

The radar-beacon misalignment program was used to collect the statistical data describing the misalignment problem for CD-record tapes RUN 001 through RUN 006. Table 8.20 lists the tapes, the analysis time intervals, range intervals, and azimuth sector intervals for each data collection. The range limits and azimuth limits were selected in each case to restrict the analysis to the region with low radar clutter where both beacon and radar data were being processed. Figure 8.48 is the resulting normalized histogram of

TABLE 8.20

DATA COLLECTED FOR RADAR-BEACON MISALIGNMENT ANALYSIS

CD-RECORDS	ANALYSIS TIME		ANALYSIS RANGE (NMI)		ANALYSIS AZIMUTH SECTOR (DEG)	
	START	STOP	MIN	MAX	START	STOP
RUN 001	9:52:00	10:12:00	25	256	0	360
RUN 002	10:58:00	11:16:00	40	256	0	360
RUN 003	13:08:00	13:28:00	32	256	0	360
RUN 04A	14:34:00	14:54:00	30	256	0	360
RUN 04B	15:19:00	15:38:00	32	256	0	360
RUN 04C	15:43:00	15:56:00	32	256	0	360
RUN 005	10:13:00	10:33:00	75	256	90	350
RUN 006	11:18:00	11:38:00	90	170	225	135

the search target report azimuth separation from the corresponding beacon report resulting from the analysis of tape RUN 04A. A 1/2 mile offset in range was purposely inserted in this data. The histogram covers azimuth from -10° to +10°. For most of the azimuth separation bins, the frequency (normalized to 1) is .002 or .003. These are attributed to the detection of misalignments caused by incorrectly associating radar clutter reports with a beacon report which would otherwise not have a corresponding radar report (the association being done by the analysis program, not the CD). In other words, for these beacon targets, a radar target was found within the window about the beacon target that was searched, but the radar report was probably caused by clutter or noise and not related to the beacon target. Several bins exceed the average frequency at smaller azimuth separations. The separation occurring the most (.708) was in the zero bin which extend from -.278° to +.278° (about +3 to -3 ACPs). The spread in azimuth separations is very concentrated at small azimuths indicating good azimuth alignment. The histogram is not entirely symmetric and a slight bias to the right (positive azimuths) is evident. This means that search reports are tending to occur at slightly higher azimuths than the corresponding beacon reports. This slight azimuth offset has a negligible, if any effect on the correlation of radar and beacon returns because the returns from the radar and beacon receiver is processed over an azimuth interval exceeding the offsets. The reported azimuths are merely the results of centroiding the returns as described in Section 8.1.2. The beacon azimuth correction factor may be slightly misaligned. However, the correction factor can be adjusted only to a resolution of 1 ACP so that the bias can never be completely removed. This, of course, is not significant since 1 ACP is negligible. The average search azimuth displacement for misalignments was 0.08° or about 1 ACP. The azimuth separation histogram of Figure 8.48 is fairly typical of all the tapes analyzed. The major conclusion to be drawn from the azimuth separation histogram is that azimuthal misalignment is not sufficiently large to prevent radar-beacon correlation which is as expected. Assuming typical target run length on the order of 30 ACPs, an offset on the order of 3° is required to prevent correlation. No such offsets were reached with any significant frequency in any of the data.

Figure 8.49 presents the normalized range separation histogram for the analysis of RUN 04A. With the exception of RUN 006, discussed later, this histogram is typical of all the tapes analyzed. The range biases are at intervals of 1/8 nmi, the resolution to which the ranges are reported.

It is immediately evident that the offset of -1/2 nmi occurs most frequently. This corresponds to the intentionally inserted offset of 1/2 nmi. However, differences of -3/8 nmi and -5/8 nmi also occur with a non trivial frequency. It is obvious that if a beacon target falls in a certain 1/8 nmi bin, and if the search report is exactly -1/2 nmi away it will fall in the 1/8 nmi bin that is 1/2 nmi below the beacon range cell. On the other hand, consider what would happen if the offset were, say -9/16 nmi.

FIGURE 8.48

NORMALIZED HISTOGRAM OF SEARCH TARGET AZIMUTH DISPLACEMENT (MISALIGNMENT ONLY) FOR RUN 04A

```
SEARCH TARGET AZIMUTH DISPLACEMENT(MISALIGNED ONLY)
  AZMUTH*  PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
  -9.998    0.001 /
  -9.442    0.002 /
  -8.887    0.002 /
  -8.331    0.002 /
  -7.776    0.003 /
  -7.220    0.003 /
  -6.665    0.002 /
  -6.110    0.003 /
  -5.554    0.003 /
  -4.999    0.003 /
  -4.443    0.003 /
  -3.888    0.003 /
  -3.333    0.005 /
  -2.777    0.004 /
  -2.222    0.004 /
  -1.666    0.009 /
  -1.111    0.017 /X
  -0.555    0.047 /XXXX
   0.000    0.708 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   0.555    0.107 /XXXXXXXXXXX
   1.111    0.013 /X
   1.666    0.009 /
   2.222    0.005 /
   2.777    0.005 /
   3.333    0.004 /
   3.888    0.003 /
   4.443    0.003 /
   4.999    0.003 /
   5.554    0.003 /
   6.110    0.003 /
   6.665    0.003 /
   7.220    0.003 /
   7.776    0.003 /
   8.331    0.003 /
   8.887    0.003 /
   9.442    0.002 /
   9.998    0.001 /
ENTRIES OUTSIDE OF TABLE:      0
```

*AZIMUTH IN DEGREES

FIGURE 8.49

NORMALIZED HISTOGRAM OF SEARCH TARGET RANGE DISPLACEMENT (MISALIGNMENT ONLY) FOR RUN 04A

```
SEARCH TARGET RANGE DISPLACEMENT(MISALIGNED ONLY)
RANGE(nm)   PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
 -1.500     0.005 /
 -1.375     0.005 /
 -1.250     0.004 /
 -1.125     0.007 /
 -1.000     0.008 /
 -0.875     0.008 /
 -0.750     0.006 /
 -0.625     0.044 /XXXXX
 -0.500     0.618 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 -0.375     0.207 /XXXXXXXXXXXXXXXXXXXXXXX
 -0.250     0.008 /
 -0.125     0.005 /
  0.000     0.002 /
  0.125     0.005 /
  0.250     0.005 /
  0.375     0.007 /
  0.500     0.006 /
  0.625     0.005 /
  0.750     0.007 /
  0.875     0.007 /
  1.000     0.006 /
  1.125     0.007 /
  1.250     0.006 /
  1.375     0.005 /
  1.500     0.005 /
ENTRIES OUTSIDE OF TABLE:      0
```

The possible results are illustrated by Figures 8.50a and 8.50b. In these figures, range space is divided into 1/8 nmi bins. Positions of the beacon target X_B and the search target X_S, where X_S is 9/16 nmi below X_B are illustrated for two positions of X_B relative to the 1/8 nmi bin boundaries. The range for the radar and beacon targets are reported by the CD accurate to 1/8 nmi determined by which 1/8 nmi range bin they fall in. The absolute value of the range difference that will be computed by subtracting the beacon range reported by the CD from the corresponding search range reported by the CD can be determined from Figure 8.50a and 8.50b by counting the number of 1/8 nmi range bin boundaries between X_B and X_S and multiply the result by 1/8 nmi. In Figure 8.50a, X_B occurs close to the lower boundary of a bin. In this case, there are five boundaries between X_B and X_S so the absolute value of the range difference is 5/8. For the histogram of Figure 8.49 the data was accumulated by subtracting the reported beacon range from the reported search range. In this case, a point occurs in the -5/8 nmi histogram bin. Note that for X_B close to the upper 1/8 nmi bin boundary, as shown by 8.42b, with the same offset of -9/16, now a point gets put in the -1/2 nmi histogram bin. Also note that with this constant offset only values of -5/8 and -1/2 can be obtained. A difference of -3/8 cannot be computed. Likewise, a constant value of, say 7/16 nmi, would allow difference of -1/2 nmi and -3/8 nmi to be obtained but not -5/8 nmi. The fact that offsets of -3/8, -4/8 and -5/8 nmi were observed with a non trivial frequency shows that the offset is not constant, but rather is time varying so that it is sometimes larger than -1/2 nmi and sometimes smaller than -1/2 nmi.

Furthermore, since the histogram is not symmetric around the -1/2 nmi difference bin, it can be assumed that the offset is not symmetrically varying around -1/2 nmi, even though this was the value of the constant offset. It is reasoned that the effective constant offset is -1/2 nmi plus some small constant value "i" so that the constant offset is given by (-1/2 + i). The time varying offset most likely has a symmetric distribution about the point (-1/2 + i).

The range separation histogram of Figure 8.49 is typical of all the data taken and the following conclusions can be made.

First, the maximum radar reinforcement rate will be achieved when the constant offset is zero. Second, even if every beacon report has a corresponding radar return, 100% radar reinforcement cannot be attained by removing the constant offset because a time varying offset exists in the system. Finally, the fact that the radar blip scan is less than one will also reduce radar reinforcement.

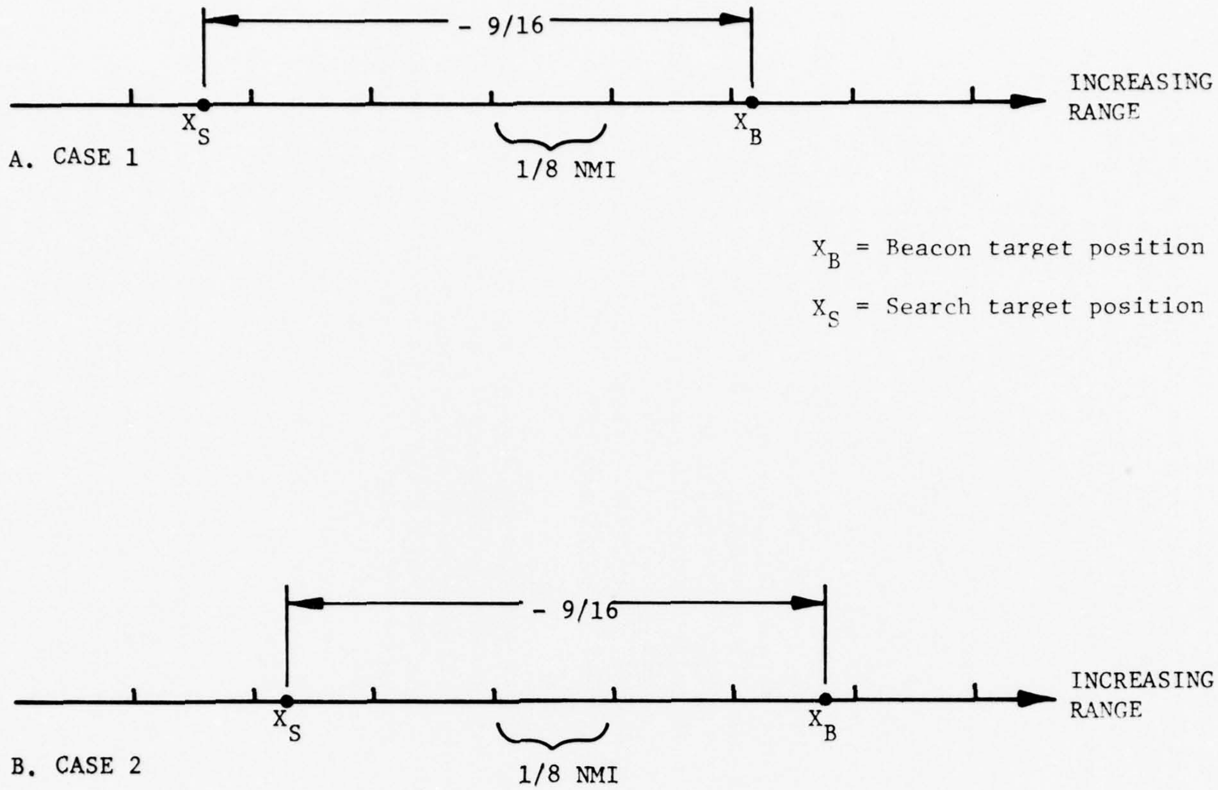


FIGURE 8.50

SEARCH RANGE OFFSET OF -9/16 nm

Using the data collected some loose bounds can be put on the reinforcement rate. The size of the bins in the range separation histograms collected is 1/8 nmi. Radar-beacon correlation takes place for returns in the same range cell, which is 1/4 nmi representing two of the histogram range separation bins. Thus the range offset in the CD can be adjusted so that at least all the misalignments detected with range separations in any two adjacent bins can be correlated. Naturally, the two adjacent range separations occurring most frequently are selected. From Figure 8.49, for RUN 04A, these separations are -3/8 nmi and -1/2 nmi with frequencies (normalized to 1 for the whole histogram) of 0.618 and 0.207 respectively so that a total of at least 0.825 of the total detected misalignments can be correlated. Therefore, of the 13833 detected misalignments, at least (.835) x 13833 = 11412 radar-beacon pairs can be correlated. A total of 20370 beacon reports were counted. Hence the ratio of 11412 to 20370 yields a lower bound (.560) that by proper offset adjustment the rate will be larger. An upper bound on the maximum number of misalignments can be obtained by including those histogram bin entries detected at one of the separations occurring adjacent to the two largest ones already chosen. For RUN 04A, the largest bin adjacent to either of the chosen bins, 3/8 and 1/2 nmi, is 5/8 nmi with a frequency of .044. Summing all three gives .044 + .618 + .207 = 0.869. Therefore, no more than 0.869 of the 13833 (which is 12021) associated radar-beacon pairs can be correlated. Dividing this by the 20370 beacon reports gives (12021 ÷ (20370) = .590 which is an upper bound on the maximum obtainable radar reinforcement rate for the data of RUN 04A, assuming that the constant radar-beacon range offset is completely removed by adjustment.

Table 8.21 tabulates, for tapes RUN 001 through RUN 006, the computed upper and lower bounds, the total detected misalignments, and the total beacon target reports. In the cases where the range offsets present were larger than 1/4 nmi, the radar reinforcement rate was negligible so the bounds were computed as described. On other tapes, the number of radar reinforcements that occurred was larger than the number of detected misalignments. In these cases, beacon reports that were radar reinforced were assumed to occupy two 1/8 nmi bins and were considered a lower bound on the maximum. The upper bound is obtained by closing the larger of the two bins adjacent to the zero separation bin and adding it to the lower bound results.

The bounds are generally between fifty to sixty percent. This is obviously a very low figure. There are several factors which may contribute to this low rate. First is the fact that the blip-scan ratio for the radar is less than the ratio for beacon (see Section 7) so some valid beacon reports exist that simply had no associated radar report. Next, the total measured beacon report ambiguity rate was, in some cases, close to four or five percent. This means that approximately four or five percent of the total beacon targets have one or more reports associated with them which do not have as associated radar report. Finally, the observed time varying offset prevents 100% correlation even when the average offset is zero for all beacon reports that have an associated radar report.

TABLE 8.21

RADAR REINFORCEMENT RATE BOUNDS

(Maximum Radar Reinforcement Rate Obtainable Lies Between These Bounds for the Data Collection)

CD-RECORDS	LOWER BOUND	UPPER BOUND	DETECTED MISALIGNMENTS	TOTAL BEACON REPORTS	RADAR REINFORCED
RUN 001	0.515	0.697	3643	16108	8302
RUN 002	0.639	0.649	12996	18645	250
RUN 003	.502	0.526	11210	18253	584
RUN 04A	0.560	0.590	13833	20370	335
RUN 04B	0.550	0.572	13299	19615	390
RUN 04C	0.539	0.563	10201	15177	303
RUN 005	0.428	0.441	1904	3599	34
RUN 006	0.482	0.489	2509	3450	29

FIGURE 8.51

NORMALIZED HISTOGRAM OF SEARCH TARGET RANGE DISPLACEMENT (MISALIGNMENT ONLY) FOR RUN 006

```
SEARCH TARGET RANGE DISPLACEMENT(MISALIGNED ONLY)
RANGE(nm)   PERCNT  +----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
  -1.500    0.003 /
  -1.375    0.002 /
  -1.250    0.002 /
  -1.125    0.004 /
  -1.000    0.002 /
  -0.875    0.002 /
  -0.750    0.000 /
  -0.625    0.010 /XX
  -0.500    0.301 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  -0.375    0.362 /XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  -0.250    0.009 /X
  -0.125    0.002 /
   0.000    0.003 /
   0.125    0.002 /
   0.250    0.003 /
   0.375    0.002 /
   0.500    0.003 /
   0.625    0.004 /
   0.750    0.005 /X
   0.875    0.033 /XXXXXX
   1.000    0.091 /XXXXXXXXXXXXXXXXXX
   1.125    0.079 /XXXXXXXXXXXXXXXX
   1.250    0.051 /XXXXXXXXXX
   1.375    0.017 /XXX
   1.500    0.006 /X
ENTRIES OUTSIDE OF TABLE:     2
```

8.4.4.2 Discussion of Range and Azimuth Separation Characteristics for RUN 006

For tapes RUN 001 through RUN 005, the search target range separation histograms were similar. That is, the separations occurring with largest frequencies were confined to two or three adjacent 1/8 nmi bins. The results for RUN 006, shown by Figure 8.51, are somewhat different. As the figure shows, there is the characteristic concentration in several adjacent bins, the largest two being at -1/2 nmi and -3/8 nmi. However, separations clustering around a mile are also occurring with non trivial frequencies. Further consideration is required to explain this phenomena.

Due to time limitations, this anomaly will not be fully investigated; however, it should be noted that during the analysis of range split azimuth separation characteristics, it was indicated that most of the results showed azimuth separation usually less than ±3°. Yet, as Table 8.19 shows, RUN 006 had a significant number of these range split type ambiguities occurring with azimuth separations larger than 3°. The two beacon reports in these ambiguities may be generated by some mechanism not related to the usual range split generation. Perhaps they are a result of a reflection problem. The occurrence of the unusual search range displacement for tape RUN 006 may be somehow tied in to what is shown in Table 8.19. This was not considered further due to limited time.

8.4.5 Missing Reports, Jagged Tracks, Code Changes

8.4.5.1 Introduction

Missing reports, jagged tracks, and code changes all involve comparison of corresponding report data from successive scans. In order to study these anomalies at the target report level, the data must be tracked. To study missing reports, the data must be tracked to determine that a track exists and that on a particular scan a report did not occur on the track. In the case of jagged track analysis, the reports must be tracked to produce a smooth flight path so that the deviation of the reports from that smooth path can be considered. For code change study, the data must be tracked so that a track code can be established. In this way, deviations from the tracked code can be observed.

A single computer program, the TRQA program described in Section 7.0, was developed to collect statistical data on these problems for the use in analysis of them. The program was not entirely completed before funding for this analysis was exhausted and, as a consequence, only limited analysis was done. The only results available are those obtained during testing and debugging of the TRQA program. All of the data presented here, with the exception of jagged track data, was collected from the Los Angeles ARSR, which is an operational site. Consequently, it represents a site actually in the field.

8.4.5.2 Missing Reports

A measure of the frequency of missing reports is the ratio of missing reports to the total number of scans. The number of beacon fades on beacon tracks is equivalent to the number of missing reports, and is given by Table 7.21 as 3225. The total number of scans or beacon tracks, given by Table 7.19 is 24191. The ratio times 100 percent is given in Table 7.21 as the percent of scans where beacon fades occurred in a beacon track and is 13.33 percent.

At the report level, there is very little that can be extracted from the data as to the cause of the missing reports. The next few paragraphs will consider some additional data to say what little can be extracted as to the nature of the cause of missing reports. Another quantity measured was the number of beacon fades, or missing reports, on beacon tracks that were backed up; i.e., filled in, by radar reports. In cases where a radar report corresponding to a missing beacon report was generated, terrain shielding of the target can be ruled out as the cause of the missing report, since terrain shielding would prevent both the radar and beacon from seeing the target. The other case for beacon fades occur when both a radar and beacon report are both not present. As Figure 7.19 shows, when the beacon reports are missing only 34.8 percent (percent beacon fades within beacon tracks backed up with radar reports, Figure 7.21) are seen by the radar.

Stated another way, there are about 13.3 percent missing beacon reports. For these beacon targets not seen by the beacon sensor, the radar sees 34.8 percent. Therefore, at least 34.8 percent of the missing beacon reports were not caused by terrain shielding of the target, or any other type of shielding that would cause both the radar and beacon sensor to both lose the target.

8.4.5.3 Jagged Tracks

The jaggedness of tracks was determined by first tracking the reports. A smooth flight path was then estimated by fitting a second order polynomial to the report position in each track. Histogram data range deviation and azimuth deviations from scan-scan report position predicted along the smooth track was then collected.

Figure 7.14 presents the range deviations of beacon reports from moving tracks. Figure 7.17 present the azimuth deviations of beacon reports from moving tracks. These were developed from data taken at NAFEC.

As Figure 7.14 shows, the absolute value of the scan-to-scan deviations in range from the predicted position was never more than 0.13 nmi. The range bin of Figure 7.14, although labeled to two decimal places, are actually 1/8 nmi bins, thus the deviation was really never more than ±1/8 nmi, which is the resolution to which the data is reported. With the present resolution of the system, no improvement can be made upon this result. It may be noticed that the range deviation is not symmetric about

zero, but rather the ±1/8 nmi bin has a higher frequency than the -1/8 nmi bin. This is explained by realizing that the deviations are from a smoothed track position, which was developed from both radar and beacon reports. The radar reports, it turns out, are slightly biased towards the negative range displacements (see Figure 7.13).

Thus the smoothed track is a result of a weighted average of both radar and beacon reports. The fact that the beacon range is skewed to the right, and the radar range is skewed to the left is a result of an average range offset between the beacon and radar reports.

Thus, the conclusion is that the range deviations from the smoothed track for beacon reports is as good as can be expected for the data taken.

The azimuth data deviation histogram for beacon reports is similarly skewed to the right (Figure 7.17) while the azimuth deviation data for radar is skewed to the left. Notice that the azimuth deviation data for the beacon report is between -0.6 degrees and +0.8 degrees. If it is assumed that the deviations are indeed symmetric about ±0.7 degrees, This is about ±9 ACPs deviation from a smoothed track. At a range of 150 nmi, this can be a deviation of almost 2 nmi tangentially and may be significant to the air traffic controller. Thus, azimuth deviations may be the primary cause of track jaggedness that was observed using the display. It is possible that an improved centroiding algorithm could improve the situation.

The results are only preliminary. However, summarizing for the preliminary results, jagged tracks are caused by azimuth deviations. At 150 nmi, the observed target position can deviate almost ±2 nmi tangentially on a display.

8.4.5.4 Code Change Statistics

Code change statistics, collected from Los Angeles data, are given by Table 7.21. The ratio of beacon reports with a code not consistent with the track code to the number of beacon reports on beacon tracks (given by CODE DIFFERENCES/NUMBER OF BEACON REPORTS ON BEACON TRACKS, Table 7.21) was 0.047 or 4.7 percent. Over half these, 51.6 percent given by PERCENT OF CODE DIFFERENCES WHICH ARE ZERO, Figure 7.21), have a code of 0000. This is the code outputted by the CD when the received beacon video was sufficiently garbled to prevent decoding of the data. The other half were reported incorrectly as some non zero code. These were probably a result of garbling, but not recognizable garbling to the CD. Thus, about 2.3 percent of the reported codes were garbled and incorrect, but not recognized as such by the CD. The beacon codes are composed of 12 binary bits. Hamming distance is the number of bit positions in which the incorrect code differs from the correct code and can take on values between one and twelve inclusively. The histogram of the frequency of each hamming distance between one and twelve shows that the most frequent distance was one. Thus most of the codes were wrongly reported by only one bit position. Distance values between two and seven occurred with about the same frequency. Very few of the code changes had distances above seven.

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8.5 ANALYSIS OF BEACON REPLIES

8.5.1 Introduction

The analysis of beacon replies is the second phase of the beacon performance analysis as described in Section 8.1. Corresponding to each of the selected target report anomalies, a group of target reports were to have been selected and an analysis of the associated replies performed for this portion of the beacon performance analysis. Problems with the recording of the Mode 2 tapes containing the reply data prevented the analysis from being started unfortunately, until shortly before suspension of the investigation efforts. Some tapes were finally obtained and a preliminary analysis was completed, though, using the Mode 2 tape display system, and some very interesting anomalies were documented. These anomalies generally raise more questions than they answer, but are nonetheless invaluable as far as indicating what steps must be taken before the reply data can be intelligently utilized to its maximum potential.

In discussion of the documented examples, the actual CD processing is considered in detail and the way in which the examples show anomalous CD behavior is indicated. It must be understood, however, that the reply data is extracted by the AI, which may be introducing its own problems to the situation. This fact will be pointed out where it applies.

8.5.2 Mode 2 Tape Data

Information on both reports and replies are recorded on the Mode 2 tapes. The report and reply data contain information pertaining to the CD processing that occurred, such as validation, run length, etc. It may, therefore, be prudent for the reader to review the CD processing of beacon video presented in Section 8.1.2 so that the meaning of the data discussed here will be more easily understood.

Table 8.22 presents a typical report message and typical reply message as they are printed out by the Mode 2 Reply Display Analysis Program from a Mode 2 tape. The data on the tape are written in records alternately containing report information and reply information. For the record containing reports, each report is called a report message. The report shown in Table 8.22 was message 15 (under column MSG messages start from number 1 on each report record) on record 3 (under column REC) of the Mode 2 tape being read.

TABLE 8.22

MOI'E 2 TAPE DATA

Typical Report Message

REC	MSG	TYPE	AZIMUTH	RANGE	RUN LNG	MOTE	FAA	AF	SRCH RINF	MODE 2 VAL	MODE 2 CODE	MODE 3A VAL	MODE 3A CODE	MODE C VAL	MODE C ALTITUDE
3	15	BCON	32.871	101.875	34	0	1	1	1	0		1	3710	1	8200

Typical Reply Message

REC	SWP	MSG	BEARING DEGREES	BEARING ACP's	RANGE NMI	MODE	CODE (ALT)	BRACKET DETECTIONS	SPI	GARBLE
4	105	2	31.025	353	101.844	3/A	3710	100000000000000	0	0

TYPE indicates either a radar report (RAD) or beacon report (BCON). Next, the range and azimuth of the report are given. This range and azimuth correspond exactly with the target report data put out by the CD for this report.

The number under the RUN LNG is the target run length which is computed as follows:

$$\text{RUN LENGTH} = (\text{UNCORRECTED CENTER AZIMUTH} - \text{AZ START}) \tag{8-1}$$

where UNCORRECTED CENTER AZIMUTH and AZ START

are as defined in Section 8.12. The run length for this target report was 34.

The MOTE flag is listed in the MOTE column. This flagging occurs for certain target reports when MOTE processing is enabled, which it was not for any of the data taken.

The FAA bit is "one" indicating the target report is of concern to the FAA. The AF bit is set indicating that the report is of concern to military facilities as well.

The column labeled SRCH RINF lists the search reinforced flag. For beacon target reports, this will be "one" whenever radar returns were associated with the beacon replies generating this report. When it is set, it usually means that the search radar, as well as the beacon, detected the target. The only time that this is not the case is when radar hits not coming from the beacon target are incorrectly associated with the target. The decoded information for each mode which was interrogated and validated is listed next for Modes 2, 3/A, and C. For each mode, the validation bit will be "one" in the VAL column when the information was validated as described in Section 8.1.2 and the corresponding information will be outputted.

Next, a typical reply message is listed. In each record containing reply data, the replies are organized in sweeps. Thus, for each interrogation, a sweep message occurs, followed by all the replies received during that sweep. The reply listed in Table 8.22 occurred on sweep 105 (under column SWP, sweeps numbered from one on each new reply record) of record four (column REC) of the Mode 2 tape being read. Here, the message number 2 under MSG, designates that this reply was the second reply received during sweep 105. The bearing is listed in both degrees and ACP's, and range is given in nautical miles. The bearing is determined from the sweep message, which was transmitted to the AI from the CD at the beginning of the sweep and is the antenna position in ACP's when the interrogation was transmitted. The actual bearing of the received reply may be slightly greater than this as the antenna is constantly rotating during the sweep.

The range, given in nautical miles, is determined from a range counter other than the ARTG range counter in the CD but which is counting at the same rate as the ARTG counter. The range indicated by the counter is trapped out immediately upon the occurrence of the reply framing pulses as detected by the CD.

Next, the mode of the reply is given (under MODE) along with associated information under CODE (ALT). The mode is determined when the sweep message is generated and is the mode which was interrogated. All replies within the same sweep will have the same mode.

The next column presents the bracket detection data. This is developed as described below. At the occurrence of a beacon reply, the first bit or second bit of a 15-bit bracket shift register is set. If a potentially garbled code occurs and if the bracket occurrence is 200 nsec late from the nominal sample time (F_2 position with respect to F_1) the second bit in the 15-bit shift register is set. Otherwise the first bit is set.

The bracket shift register shifts one position each BRG code sample interval (1.455 μsec). Once initiated, the shift register will operate for 15 code sample intervals and will load bracket occurrence during any of these intervals. The contents of this register after fifteen intervals is used to form the number in this comumn and provides a record of any brackets which may occur due either to overlapped, interleaved or closely spaced replies.

For beacon targets detected in the clear the right half of the first beacon data word is 100 0000 0000 0000. The "one" in the leftmost bit position is called "own bit" since it represents the bracket detections for the reply message at hand. For targets which are interleaved or overlapped the first target report will contain a "one" as shown above and a second "one" in at least one of the other bit positions of the word except in the special case noted where the second bit of the shift register is loaded instead of the first bit. In this case "own bit" will be missing entirely.

The value in the SPI columns is set to "one" whenever a pulse was detected in the SPI bit position of a reply. This indicates, normally, that the pilot has activated the "ident" feature of the transponder. The garble bit is set in the GARBLE column whenever the BRG detects a garbled condition for a reply.

Figure 8.52 is a display of a sector of report data and reply data from a sample Mode 2 tape of Elwood data received by the Laboratory. All the data are plotted in PPI fashion on the display. Target reports are shown in green, target report ambiguities are green X, Mode 3/A replies are red and Mode C replies are blue. The blocks of data do not coincide exactly, so that the first part of the sector of replies (azimuth measured clockwise from north) has no corresponding report data displayed, and the last part of the sector of report data has no corresponding replies displayed. Notice the high density of replies as compared to the reports generated. Many of these replies are coming from transponders replying to interrogations by other sites and are called fruit.

About 29 replies are transmitted when an interrogator antenna mainbeam scans past a target. The Elwood CD must process all these replies and determine which replies are coming from a transponder interrogated by the ATCBI at its site, and which are not. This is done by azimuth integration of replies at the same range by use of a sliding window. Since the PRF of interrogators at other sites is slightly different from the Elwood site, successive replies received from a transponder interrogated by another site will not appear at the same range. Those coming from a transponder interrogated by the Elwood ATCBI will be at the same range, and azimuth integration will produce a target report. The Elwood CD must process all the replies and determine the range, azimuth, beacon code and altitude of the transponder equipped targets within its range (256 nmi).

8.5.3 Example of Centroiding Analysis

In several of the documented anomalies that follow, an analysis of the CD detection and centroiding is done at the sliding window level, using the reply data supplied by AI as the data base. The approach is to select a target report of interest and list the corresponding replies. Using these replies, the contents of the sliding window associated with the generation of the report is written for each sweep of interest.

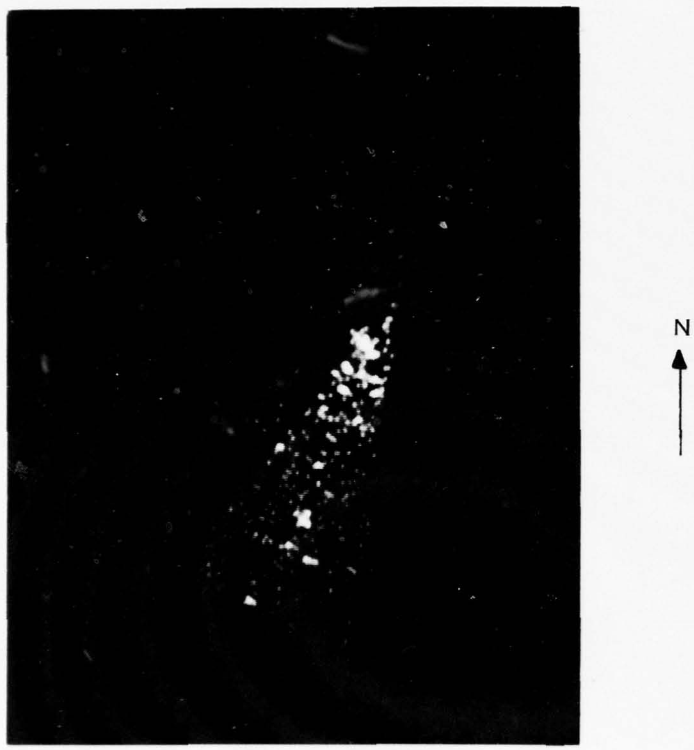
Since T_T and T_L are known, the centroiding of the target report may be verified. An example of this type of analysis is presented here for a report not exhibiting any problems.

Table 8.23 lists the beacon target report and corresponding replies being considered. This data was obtained using the Mode 2 tape display-analysis system. The report and corresponding replies were displayed and the data was extracted using the ball tab hook feature of the display. Figure 8.53 is the display of the data at hand.

FIGURE 8.52

DISPLAY OF AUXILIARY INTERPRETER REPLY TAPE DATA

ELWD B2 - BLOCK 141, 142, 143



* 75 NMI RINGS
* REPORTS - GREEN (OR WHITE)
* 3/A - REPLIES - RED
* C REPLIES - BLUE
* AMBIGUITIES - GREEN, X

TABLE 8.23

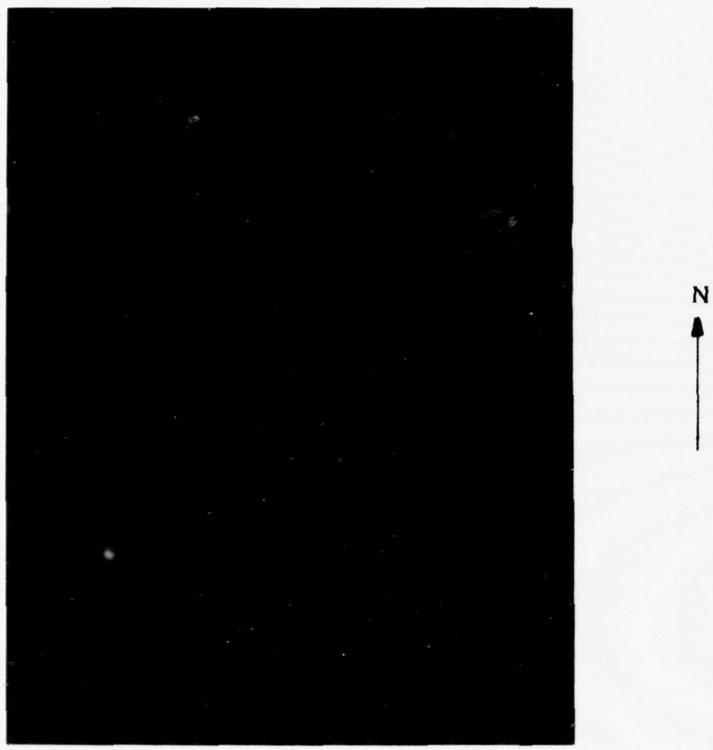
REPORT AND ASSOCIATED REPLIES FROM TAPE MODE 2 12/16/75 #1

REC	MSG	TYPE	AZIMUTH	RANGE	RUN LNG	MOTE	FAA	AF	SRCH RINF	MODE 2 VAL	MODE 2 CODE	MODE 3A VAL	MODE 3A CODE	MODE C VAL	MODE C ALTITUDE
261	6	BCON	246.797	133.125	θγ	0	1	1	0	0		1	3763	0	

REC	SWP	MSG	|---BEARING---| DEGREES	ACP|S	RANGE NAUT MI	MODE	CODE (ALT)	BRACKET DETECTION	SPI	GARBLE
262	34	3	245.215	2790	133.156	3A	3763	100000000000000	0	0
262	35	3	245.303	2791	133.125	C	13500	100000000000000	0	0
262	36	3	245.391	2792	133.156	3A	3763	100000000000000	0	0
262	37	3	245.566	2794	133.125	3A	3763	100000000000000	0	0
262	38	3	245.654	2795	133.125	C	13500	100000000000000	0	0
262	39	2	245.742	2796	133.125	3A	3763	100000000000000	0	0
262	40	3	245.830	2797	133.156	3A	3763	100000000000000	0	0
262	41	3	245.918	2798	132.063	C	107900*	100000000000000	0	0
262	42	3	246.006	2799	133.125	3A	3763	100000000000000	0	0
262	43	3	246.182	2801	133.125	3A	3763	100000000000000	0	0
262	44	4	246.270	2802	133.125	C	13500	100000000000000	0	0
262	45	5	246.357	2803	133.156	3A	3763	100000000000000	0	0
262	46	4	246.445	2804	133.125	3A	3763	100000000000000	0	0
262	48	5	246.621	2806	133.156	3A	3763	100000000000000	0	0
262	51	2	246.973	2810	135.156	3A	3737	100000000000000	0	0

FIGURE 8.53

TARGET REPEAT AND REPLIES



TAPE – MODE 2 12/16/75 NO. 1

RANGE RINGS INTERVAL – 2 NMI

COLOR CODE –

REPORT – GREEN

MODE 3/A REPLIES – RED

MODE C REPLIES – BLUE

DATA LISTING – SEE TABLE 8–19

In addition to the listing given in Table 8.23, a complete listing of the reply record containing the replies was obtained. This is necessary to determine the azimuth in ACP's for sweeps other than those listed in Table 8.23 because a one-to-one correspondence between sweeps and ACP increments does not exist. There are 4096 ACP's per scan but at a PRF of 360/sec and a scan rate of 9.6 sec/scan there are only 3456 sweeps per scan. Consequently, for some pairs of successive sweeps, the azimuth will increment by two ACP's instead of one.

There is usually a sufficient amount of replies on fruit present so that at least one reply will be obtained on every sweep and by listing the complete record of replies the corresponding azimuth on every sweep may be determined.

The analysis proceeds by first verifying that the sliding window of interest was initially all zero before the occurrence of the first Mode 3/A reply listed in Table 8.23. This is done by examining the complete list of replies for the eleven Mode 3/A sweeps prior to the first Mode 3/A sweep in Table 8.23 which is sweep number 34. The sliding window of interest will be empty if no Mode 3/A replies occur within a 1/4 nmi of any of the Mode 3/A replies listed in Table 8.16 for the eleven Mode 3/A sweeps previous to sweep 34. This procedure was followed and the sliding window was found to be empty.

Next, a table is set up to list the sliding window contents after each sweep. This table is shown as Table 8.24. The table lists the eleven bits of the sliding window, the sweep number, the azimuth in ACP's and mode of the interrogation for that sweep. In this example, the sliding window word shown in Table 8.24, is shifted to the left after each Mode 3/A sweep and the hits and misses are shifted into the word from the right. The window is shown in Table 8.24 as containing no hits (eleven zeroes) on sweep 33. As Table 8.16 shows, sweep 34 is a Mode 3/A sweep and contains a hit (Mode 3/A reply). This is indicated by entering a one into the rightmost bit position of the sliding window. Sweep 35 is a Mode C sweep and does not affect the sliding window contents. Sweep 36 is a Mode 3/A sweep and a reply was received. The sliding window is shifted left by one bit, moving the first one into the bit position second from the rightmost bit position. The received reply is recorded by entering another one into the window in the rightmost bit position. This procedure is continued until sufficient misses occur to enter all zeroes back in the sliding window. A miss, for example, occurred on sweep 49, which was a Mode 3/A sweep. In this case, the contents of the word were shifted left, and a zero was entered in the rightmost position.

TABLE 8.24

SLIDING WINDOW ANALYSIS FOR DATA OF TABLE 8.23

WINDOW	SWEEP	ACP	MODE
0 0 0 0 0 0 0 0 0 0 0 0	33	2789	A
0 0 0 0 0 0 0 0 0 0 0 1	34	2790	A
0 0 0 0 0 0 0 0 0 0 0 1	35	2791	C
0 0 0 0 0 0 0 0 0 0 1 1	36	2792	A
0 0 0 0 0 0 0 0 0 1 1 1	37	2794	A
0 0 0 0 0 0 0 0 0 1 1 1	38	2795	C
0 0 0 0 0 0 0 0 1 1 1 1	39	2796	A
0 0 0 0 0 0 0 1 1 1 1 1	40	2797	A
0 0 0 0 0 0 0 1 1 1 1 1	41	2798	C
0 0 0 0 0 0 1 1 1 1 1 1	42	2799	A
0 0 0 0 0 1 1 1 1 1 1 1	43	2801	A
0 0 0 0 0 1 1 1 1 1 1 1	44	2802	C
0 0 0 0 1 1 1 1 1 1 1 1	45	2803	A
0 0 0 1 1 1 1 1 1 1 1 1	46	2804	A
0 0 0 1 1 1 1 1 1 1 1 1	47	2805	C
0 0 1 1 1 1 1 1 1 1 1 1	48	2806	A
1 1 1 1 1 1 1 1 1 1 1 0	49	2808	A
1 1 1 1 1 1 1 1 1 1 1 0	50	2809	C
1 1 1 1 1 1 1 1 1 1 0 1	51	2810	A
1 1 1 1 1 1 1 1 1 0 1 0	52	2811	A
1 1 1 1 1 1 1 1 1 0 1 0	53	2812	C
1 1 1 1 1 1 1 1 0 1 0 0	54	2814	A
1 1 1 1 1 1 1 0 1 0 0 0	55	2815	A
1 1 1 1 1 1 1 0 1 0 0 0	56	2816	C
1 1 1 1 1 1 0 1 0 0 0 0	57	2817	A
1 1 1 1 1 0 1 0 0 0 0 0	58	2818	A
1 1 1 1 1 0 1 0 0 0 0 0	59	2820	C
1 1 1 1 0 1 0 0 0 0 0 0	60	2821	A
1 1 1 0 1 0 0 0 0 0 0 0	61	2822	A
1 1 1 0 1 0 0 0 0 0 0 0	62	2823	C
1 1 0 1 0 0 0 0 0 0 0 0	63	2824	A
1 0 1 0 0 0 0 0 0 0 0 0	64	2826	A
1 0 1 0 0 0 0 0 0 0 0 0	65	2827	C
0 1 0 0 0 0 0 0 0 0 0 0	66	2828	A
0 0 0 0 0 0 0 0 0 0 0 0	67	2829	A

8.5.3.1 Centroid Verification

The next step is to verify the centroiding done by the CD. The corrected azimuth listed in the report record (Table 8.23) is 246.979°. This is converted to ACP's using the following equation:

$$AZ(DEG) \times \frac{4096(ACP's)}{360\ (DEG)} = AZ\ (ACP's) \qquad (8\text{-}2)$$

The result for this example is 2808 ACP's. The azimuth correction factor used by the Elwood CD is -3 ACP's. This correction is added to the uncorrected azimuth to obtain the corrected value 2808 ACP's. Therefore, the uncorrected azimuth was 2811 ACP's. The run length is 24, which was computed from Equation (8-1). Rearranging Equation (8-1) to exress the azimuth start in terms of run length and uncorrected azimuth gives

$$\text{AZ START} = \text{UNCORRECTED CENTER AZIMUTH} - \frac{\text{RUN LENGTH}}{2} \qquad (8\text{-}3)$$

The computed azimuth start for this example is 2799 ACP's. As described in Section 8.1.2, the uncorrected azimuth is determined by adding the stop azimuth to the start azimuth and dividing the sum by two, truncating the fraction of 1/2 ACP if it exists. This is given by Equation (8-4).

$$\text{UNCORRECTED CENTER AZIMUTH} = \frac{\text{AZ START} + \text{AZ STOP}}{2} \qquad (8\text{-}4)$$

where the remainder of 1/2, if present, shall be truncated. This equation is rearranged to express the stop azimuth in terms of the other quantities as shown.

$$\text{AZ STOP} = (2 \times \text{UNCORRECTED CENTER AZIMUTH}) - \text{AZ START} \qquad (8\text{-}5)$$

Taking into account the possible truncation of the fraction of 1/2 ACP, the value of AZ STOP that occurred in the CD could be the value obtained from Equation (8-5) or one ACP more. For the example at hand, this could be either 2823 or 2824 ACP's.

The data obtained or computed from the target report message is summarized below.

AZIMUTH START	: 2799 ACP's
AZIMUTH STOP	: 2823 ACP's, or 2824 ACP's
UNCORRECTED CENTER AZIMUTH	: 2811 ACP's
CORRECTED AZIMUTH	: 2808 ACP's

The final step is to compare the results obtained from the target report message with the expected results determined from listing the sliding window contents in Table 8.24. The starting azimuth, 2799 ACP's, should correspond to the azimuth at which the sliding window first reaches the target leading edge threshold T_L which is six (out of eleven) for Elwood. The sliding window of Table 8.24 reached this threshold on sweep 42. The azimuth of sweep 42, 2799 ACP's, agrees with the computed starting azimuth of 2799.

The azimuth given by each initial sweep message in the AI Mode 2 data is the azimuth, in ACP's, of the antenna at the beginning of the sweep. The azimuths used in the CD for computation of the center azimuth (i.e., the start and stop azimuths) are the antenna azimuths that existed when T_L and T_T were declared. These azimuths may be greater than or equal to the azimuths that existed when the sweep messages were issued because the antenna is constantly rotating in the direction of increasing azimuth. Thus, when a table of sliding window contents such as that of 8.24 is used to determine actual starting and ending azimuths or compared with data computed from a report message, this difference must be considered. For example, consider sweep 42 in Table 8.24 whe where the leading edge threshold is first reached. The azimuth of this sweep is 2899. The azimuth of the next sweep, 43, is 2801. Therefore, using the information from Table 8.24 alone, the leading edge threshold could have occurred at any azimuth from 2799 ACP's to 2801 ACP's. In this case, the target report message shows that the azimuth was actually 2799 ACP's.

The trailing edge threshold at Elwood is two. The azimuth stop of the target should correspond to the azimuth at which the sliding window falls to this level after reaching the leading edge threshold. This occurs on sweep 63 at an azimuth of 2824 ACP's which agrees with the azimuth computed from the target report message.

The conclusion in this case is that the CD properly processed the group of replies listed in Table 8.23 to produce a target report. The range of the replies varied between 133.125 to 133.156 nmi which is a 1/32 nmi difference, the minimum resolution of the range counter. Both of these ranges are apparently within the same 1/4 nmi range cell in the CD processing, which resulted in a report range of 133.125 nmi.

In Figure 8.53, it can be seen that the position of the target report appears displaced from the eyeballed center of the group of replies. As the previous analysis just showed, however, the centroiding was properly done. For properly replying transponders, this displacement will be consistent and can be computed. The azimuth start occurs five Mode 3/A sweeps after the first reply from the transponder, assuming no missing Mode 3/A replies. Taking into account the mode interlace of 3/A, 3/A, C this works out to an average of 7.5 sweeps after the first reply. If the transponder transmits an unbroken string of replies until the antenna mainbeam is past,

(i.e. no missing replies), the trailing edge of stop azimuth will be declared 9 Mode 3/A sweeps after the last reply, or 13.5 sweeps late. Converting sweeps to ACP's, the starting azimuth is, on the average, 8.89 ACP's after the first reply and the stop azimuth is 16 ACP's after the last reply. Equation (8-4) may be rewritten

$$\text{UNCORRECTED CENTER AZIMUTH} = \frac{(AZ,ER + 8.89) + (AZ.LR + 16)}{2} \qquad (8\text{-}6)$$

where AZ,FR = Azimuth of the first reply (ACP's)
AZ,LR = Azimuth of the last reply (ACP's).

Thus the displacement in the uncorrected azimuth is

$$\frac{8.89 + 16}{2} = 12 \text{ ACP's.}$$

When the correction factor of -3 ACP's is added, the displacement in the corrected azimuth is 9 ACP's or 0.79°.

Therefore, on the average, for properly replying transponders, the displacement of the target report from exactly half way between the *first and last replies comprising that report will be 9 ACP's or 0.79°.* This displacement is no cause for concern. It is more important that the displacement be consistent for all other computed reports so that the controller can maintain proper aircraft separation based on the data presented to him.

In the other documented examples, a similar azimuth displacement will be evident, and since it has been shown that this displacement represents normal centroiding, the normal displacement should not be allowed to distract from the other points to be made for each documented anomaly.

8.5.4 Range Split Example

Figure 8.52 presented reports and associated replies displayed from a Mode 2 tape with target report ambiguities displayed by a green X. The ambiguity in the display at 132 nmi and 205° was offset to the center of the display for a more detailed examination. The expanded display of the two reports and associated replies is shown in Figure 8.54 along with the report data. Also on the display is a small green box which is the ball tab "hook" used to extract report and reply data. The report data is included with Figure 8.54 and the associated reply data is listed in Table 8.25.

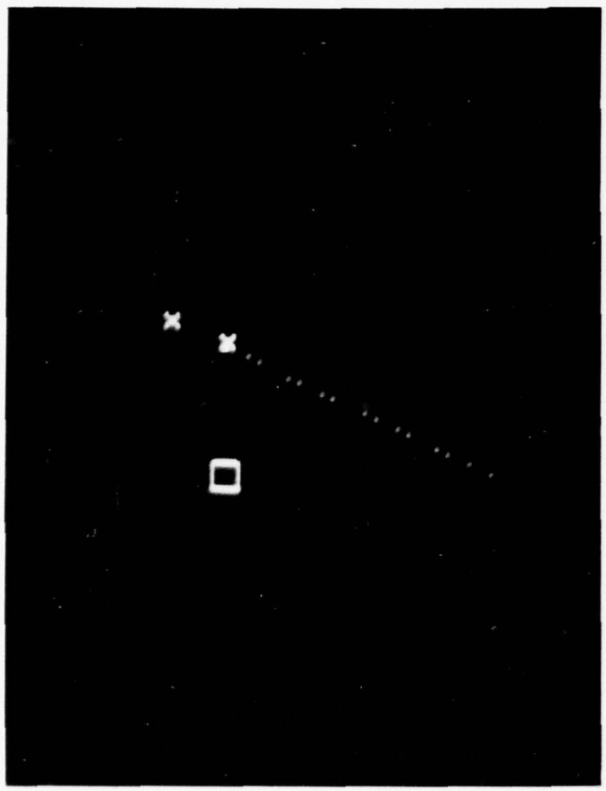
The report data is considered first. The range of reports I and II are 131.875 and 132.000 respectively, for a separation of 0.125. The azimuth separation is about 0.4°. These separations together are characteristics of what has been called a range split, assuming that the reports were generated in adjacent range cells. Considering that Table 8.25 shows no missing Mode 3/A replies, there is no reason why two reports would be generated in the same range cell. The beacon codes for each report are identical, but in one case altitude data was not validated. Presumably, the replies returning from a single airborne transponder are being randomly assigned between two adjacent range cells with sufficient quantities in each to declare a target leading edge.

Consider next the range of the replies given in Table 8.25. With the exception of the last Mode 3/A reply, all the Mode 3/A replies were reported as being at the same range by the AI. This would tend to imply that a serious problem exists with the CD processing, but this conclusion should not be hastily made. A possible explanation for this difference is as follows. First, as previously explained, the range of the replies as determined by the AI is obtained from a range counter that is separate from the range counter of the ARTG in the CD and is allowed to count at the ARTG clock rate. Furthermore, the range is "trapped" by the AI from this range counter immediately upon occurrence of the beacon F_1-F_2 bracket detection. On the other hand, the CD is determining the range by using the ARTG counter as an "address register" which assigns the replies to a core address at which the sliding window associated with the current range count is located. This assignment is done by the Memory Control Group (MCG) in the CD and is constrained to operate within fixed read-write cycles. The extra processing and timing in the CD may be introducing an additional uncertainty into the system so that while all the replies are actually seen at the same range by the AI, they may, in fact, be getting assigned randomly between adjacent range cells in the CD. Further investigation would be required to verify that this hypothesis is true.

FIGURE 8.54

REPORT RANGE SPLIT AND REPLIES (REPLY TAPE DATA)

ELWD B2 - BLOCKS 141, 142, 143



N

* 5 NMI RINGS
* 3/A - RED
* C - BLUE
* SPLIT - GREEN, X

REPORT I	REPORT II
R = 131.875	R = 132.000
AZ = 205.7	AZ = 206.1
ALT = ———	ALT = 39,100
CODE = 2630	CODE = 2630

TABLE 8.25
REPLIES RESULTING IN A RANGE SPLIT
REPLIES

RANGE	AZ	CODE	ALT	MODE
130.968	203.378	———	55,000	C
131.937	203.466	0630	———	3A
131.937	203.642	0620	———	3A
131.937	203.730	———	39,000	C
131.937	203.818	0620	———	3A
131.937	203.906	2630	———	3A
———	———	———	———	——— MISSING MODE C
131.937	204.169	0620	———	3A
131.937	204.257	2620	———	3A
131.937	204.345	———	39,100	C
131.937	204.433	0620	———	3A
131.937	204.521	0620	———	3A
131.937	204.697	———	55,000	C
131.937	204.785	0620	———	3A
131.937	204.873	2630	———	3A
131.937	204.960	———	39,100	C
131.937	205.048	2620	———	3A
131.937	205.136	2630	———	3A
131.937	205.312	———	39,100	C
131.937	205.400	2620	———	3A
131.937	205.488	2630	———	3A
131.937	205.576	———	39,100	C
131.968	205.664	2630	———	3A

Some other problems are also apparent in the reply data of Table 8.25. Both the beacon code and altitude, for example, are not being consistently reported the same. In one case a Mode C reply was completely missing.

The major point of this example is the fact that two target reports were generated from a group of replies, in a range split configuration, even though the replies as listed by the AI could not produce two reports in the CD. Presumably, timing differences in between the AI and the CD permit the AI to list the replies at the same range while the CD is assigning the replies between adjacent range cells.

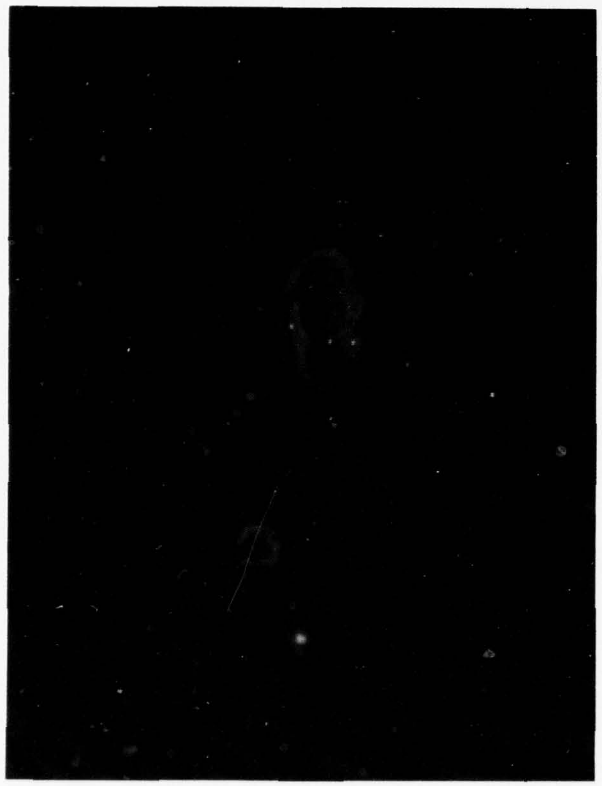
8.5.5 Two Replies in Same Range Cell on Same Sweep

Figure 8.55 is a display of another interesting target report and associated replies. The tape from which the data was made is listed in Figure 8.55 along with a label of the photo and the associated report data. The report message was message 15 in record 3 of the indicated tape. Notice that none of the beacon data validated.

The replies that produced this report are listed in Table 8.26. Look at the sweeps listed for this group of replies under the SWP column; it can be seen that a Mode 3/A reply is missing between sweeps three and five, and two Mode 3/A replies are missing between sweeps five and eight. More interesting is that two replies are listed for sweep thirteen, both of which are Mode 3/A and at the same range. In theory, this cannot happen because the CD can only process one hit or one miss for each range cell per Mode 3/A sweep. Next, consider the ranges of all of the replies. The AI is indicating replies at 56.469 nmi and 56.500 which are different by 1/32 nmi, the minimum increment of the range counter used to determine the reply ranges. An analysis of range jitter in ATCRBS is done in Section 4.2 and it is shown that the normal amount of jitter can cause the replies to vary in range from reply to reply even before they enter CD processing so that the jitter of 1/32 nmi is not considered to be unusual. The reply on sweep nine was reported at 56.000 nmi by the AI. As this is more than 0.250 nmi from the other replies it should be in a different range cell. However, as the sliding window analysis will show, this reply is apparently necessary to reach the leading edge threshold. The correct beacon code and altitude cannot be determined from the information given under the CODE (ALT) column. Several replies are indicated as garbled, though the bracket detection word never shows the presence of a potentially interfering reply.

FIGURE 8.55

ANOMALOUS REPLIES — TWO REPLIES IN SAME RANGE CELL ON SAME SWEEP



TAPE — MODE 2 12/16/75 #1
PHOTO — 1/28/76 #B

REPORT DATA —

REC	3
MSG	15
AZIMUTH	21.973
RANGE	56.500
RUN LENGTH	18
SRCH RINF	1
MODE 2	
VAL	0
CODE	
MODE 3/A	
VAL	0
CODE	
MODE C	
VAL	0
ALTITUDE	

TABLE 8.26

REPLY DATA FOR PHOTO 1/28/76 NO. B

REPLIES (FIGURE 8.55)

		BEARING		RANGE		CODE			
REC	SWP	DEGREES	ACPS	NAUT MI	MODE	(ALT)	BRACKET DETECTION	SPI	GARBLE
4	3	20.303	231	56.500	3A	0006	100000000000000	0	0
4	5	20.566	234	56.469	C	14000	100000000000000	0	0
4	8	20.830	237	56.469	C	14000	100000000000000	0	0
4	9	21.006	239	56.000	3A	0606	100000000000000	0	0
4	10	21.094	240	56.469	3A	0606	100000000000000	0	0
4	11	21.182	241	56.469	C	7300	100000000000000	0	0
4	12	21.270	242	56.469	3A	0206	100000000000000	0	1
4	13	21.357	243	56.500	3A	0602	100000000000000	0	1
4	13	21.357	243	56.500	3A	0002	100000000000000	0	1
4	14	21.533	245	56.469	C	7000	100000000000000	0	0
4	15	21.621	246	56.500	3A	0602	100000000000000	0	1

An analysis of the sliding window contents using the replies listed in Table 8.26 was done following the procedure of Section 8.5.3 and the results are given in Table 8.27. In addition to "ones" to indicate normal hits, some other symbols were used when the sliding window contents were listed for the purpose of indicating the nature of the replies. A special symbol was used for each of the following reply conditions: 1) Garbled replies, 2) Two replies at same range on same sweep and garbled, 3) A reply which sould not be in the range cell of interest. The key of Table 8.27 lists the conditions and the corresponding symbols. Also, the azimuth start and stop as computed from the target report data by the procedure in Section 8.5.3 are shown by Table 8.27. In some cases, no azimuth (under ACP column) is given for a sweep because no replies occurred on that sweep and, as a result, the azimuths of these sweeps were not listed by the Mode 2 tape display-analysis program data printout. Two potential azimuth ends are shown because of the uncertainty in pinpointing the exact azimuth end for reasons given in Section 8.5.3.

The start azimuth was computed from the report data as 244 ACP's. Since the start azimuth must occur on a Mode 3/A sweep, the only possible sweep is sweep thirteen which had an azimuth of 243 ACP's at the start of the sweep. The next highest Mode 3/A sweep, sweep fifteen, has an azimuth of 246 ACP's at the start and therefore cannot be selected. The CD, therefore, must have found six hits out of eleven in the sliding window on sweep thirteen. This is the sweep on which the two replies were both listed at the same range. The occurrence of this is indicated as a single bit position in the sliding window (because the window should only be shifted once each sweep) which is occupied by "++". Two pluses together are used to symbolize that two garbled hits have occurred at the same range on the same sweep. In addition to this anomalous event, the window also contains two normal hits, one garbled hit, and one hit which, because of its range, should not really be in this window. Since this was computed from the CD target report data as being the starting azimuth, there should be six hits in the sliding window. The only way that six hits can be counted in the sliding window of sweep thirteen is if, in addition to the two normal hits and one garbled hit which would ordinarily be counted, the reply which really belongs in another range cell is counted and the bit position occupied by ++ to indicate two replies at the range on the same sweep is counted as two bit positions, each with a hit. These anomalies are quite unexplainable within the constraints or normal CD operation. The reply at 56.000 nmi is separated from the closest of the other replies in Table 8.27 by 0.469 nmi or fifteen 1/32 nmi increments. As indicated before, the AI is trapping the range of the received replies accurate to 1/32 nmi as they are detected by the BRG in the CD. The closest that wayward reply could be to the replies at 56.469 is approaching fourteen 1/32 nmi increments or 0.438 nmi. This is well over a 1/4 nmi separation and the CD should have definitely assigned the reply to an altogether different range cell. There is no known jitter for normal CD operation between the BRG in the CD and the ARTG range

TABLE 8.27

SLIDING WINDOW HISTORY FOR 1/28/76 #B (FIGURE 8.55)

	WINDOW	SWEEP	ACP	MODE		WINDOW	SWEEP	ACP	MODE
	00000000000	2	230			01000R1+⧺+0	17	248	C
	00000000001	3	231	A		1000R1+⧺+00	18	249	A
	00000000010	4		A		000R1+⧺+000	19	251	A
	00000000010	5	234	C		000R1+⧺+000	20		C
	00000000100	6	23	A		00R1+⧺+0000	21		A
	00000001000	7	23	A		0R1+⧺+00000	22		A
	00000001000	8	23	C		0R1+⧺+00000	23		C
	0000001000R	9	239	A		R1+⧺+000000	24		A
	000001000R1	10	240	A		1+⧺+0000000	25		A
	000001000R1	11	241	C		1+⧺+0000000	26		C
	00001000R1+	12	242	A		+⧺+00000000	27		A
AZIMUTH START*	0001000R1+⧺	13	243	A		⧺+000000000	28		A
	0001000R1+⧺	14	245	C	AZIMUTH END*	⧺+000000000	29	262	C
	001000R1+⧺+	15	246	A		+0000000000	30	263	A
	01000R1+⧺+0	16	24	A		00000000000	31	265	A

* COMPUTED FROM REPORT DATA ON MODE 2 TAPE

KEY — 0 NO HIT
1 HIT
\+ GARBLED HIT
⧺ DOUBLE HIT, GARBLED
R HIT SHOULD HAVE BEEN IN ANOTHER RANGE CELL

counter which could add a sufficient deviation to cause this reply to end up in a range cell with the other replies of Table 8.27. A logical question then, is "did it really get counted in this sliding window or not?" An answer cannot be given with the available data, and further investigation is required. It is suspected, however, that either an intermittent CD failure occurred or, possibly, a failure in the AI occurred.

The pair of replies listed at the same range for the same sweep can only be partially explained. As indicated before, the difference between CD timing might be such that even though the AI indicates replies at the same range, the CD can assign them to different range cells. Thus, it is potentially possible to have two replies reported at the same range on the same sweep by the AI. The CD cannot put more than one hit in a particular range cell sliding window per sweep when functioning normally. However, as noted before, both of these hits are needed to reach the leading edge threshold of six hits. It might be suggested that a timing error in the CD caused it to process the same sliding window twice on the same sweep or the failure may be in the extraction of the reply data by the AI. In any event, the causes for the anomalies indicated here should be investigated.

This example has illustrated the following two anomalies: First, a reply which the AI indicates is separated from a group of replies by at least 0.469 nmi (which is well over the .250 nmi range cell interval) is apparently processed in the same range cell as that group of replies and used to declare a target leading edge. Second, two replies reported at the same range and the same sweep are included in that group of replies and are apparently both processed into the associated range cell sliding window. This is unusual since the CD is designed to only process and enter one hit per range cell on each sweep.

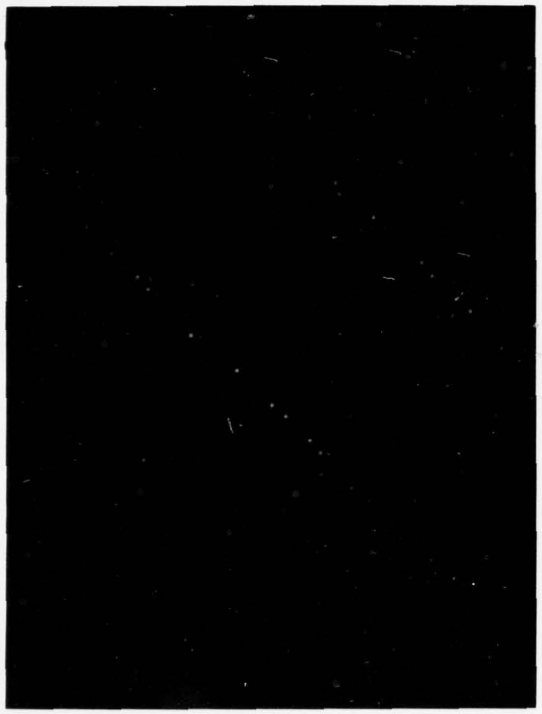
8.5.6 Improper Centroiding of a Report

Figure 8.56 illustrates photo 1/28/76 #D of a display of a report and associated replies. The anomaly to be illustrated by this example is the apparent failure of the CD to properly perform the centroiding algorithm. The report data extracted from the Mode 2 tape is listed in Figure 8.56 as well. Notice that the Mode C altitude information was not validated.

Table 8.28 lists the replies associated with the report of Figure 8.56. Using the data of Table 8.28, a sliding window analysis was done to produce Table 8.29. An analysis of the target report data yielded the indicated azimuth start and azimuth end shown on Table 8.29. All of the Mode 3/A replies used to determine the sliding window contents were reported at the same range by the AI (100.688 nmi) with the exception of the reply on sweep 228 which was reported at 100.719 nmi. For purposes of the sliding window analysis it was assumed that this reply may potentially be in a different range cell from the others and it is so indicated (see key for Table 8.29).

FIGURE 8.56

ANOMALOUS REPLIES — INCORRECT CENTROIDING



TAPE — MODE 2 12/16/75 #1
PHOTO — 1/28/76 #D

REPORT DATA —	
REC	5
MSG	6
AZIMUTH	46.230
RANGE	100.750
RUN LENGTH	26
SRCH RINF	1
MODE 2	
VAL	0
CODE	
MODE 3A	
VAL	1
CODE	2732
MODE C	
VAL	0
ALTITUDE	

TABLE 8.28

REPLY DATA FOR 1/28/76 #D

REPLIES (FIGURE 8.56)

RFC	SWP	|---BEARING---| DEGREES	ACP|S	RANGE NAUT MI	MODE	CODE (ALT)	BRACKET DETECTION	SPI	GARBLE
4	227	43.682	497	100.688	C	10200	100000000000000	0	0
4	228	43.770	498	100.719	3A	2712	100000000000000	1	0
4	229	43.945	500	100.688	3A	2732	100000000000000	0	0
4	230	44.033	501	100.688	C	10200	100000000000000	0	0
4	231	44.121	502	100.688	3A	2732	100000000000000	0	0
4	232	44.209	503	100.688	3A	2732	100000000000000	0	0
4	233	44.297	504	100.688	C	10200	100000000000000	0	0
4	235	44.561	507	100.688	3A	2732	100000000011101	1	0
4	236	44.648	508	100.688	C	10200	100010101000100	1	0
4	238	44.824	510	99.531	3A	2571	100010001100000	0	1
4	238	44.824	510	100.688	3A	2732	100000000000000	0	0
4	239	44.912	511	100.688	C	10200	100010101000100	1	0
4	240	45.088	513	100.688	3A	2732	100000000011101	1	0
4	241	45.176	514	100.688	3A	2732	100000000011101	1	0
4	242	45.264	515	100.656	C	10200	100010100000100	0	0
4	243	45.352	516	100.688	3A	2732	100000000011101	1	0
4	244	45.439	517	100.688	3A	2732	100000000011101	1	0
4	245	45.615	519	100.688	C	10200	100010101000100	1	0
4	246	45.703	520	100.688	3A	2732	100000000011101	1	0
4	247	45.791	521	100.031	3A	3410	101011000000000	0	1
4	247	45.791	521	100.688	3A	2732	100000000011101	0	1
4	248	45.879	522	100.688	C	10200	100010101000100	1	0
4	249	45.967	523	100.688	3A	2732	100000000011101	1	0
4	250	46.055	524	100.688	3A	2732	100000000011101	1	1

TABLE 8.29

SLIDING WINDOW HISTORY FOR 1/28/76 #D (FIGURE 8.56)

	WINDOW	SWEEP	ACP	MODE		WINDOW	SWEEP	ACP	MODE
	00000000000	227	497	C		11010111111	246	520	A
	R	228	498	A		1010111111+	247	521	A
	R1	229	500	A		1010111111+	248	522	C
	R1	230	501	C		010111111+1	249	523	A
	R11	231	502	A		10111111+1+	250	524	A
	R111	232	503	A		10111111+ 1+	251	526	C
	R111	233	504	C		0111111+1+0	252	527	A
	R1110	234		A		11111+1+00	253	528	A
	R11101	235	507	A		11111+1+00	254	529	C
	R11101	236	508	C		11111+1+000	255	530	A
	R111010	237		A		1111+1+0000	256	532	A
	R1110101	238	510	A		1111+1+0000	257	533	C
	R1110101	239	511	C		111+1+00000	258	534	A
	R11101011	240	513	A		11+1+000000	259	535	A
	R111010111	241	514	A		11+1+000000	260	536	C
	R111010111	242	515	C		1+1+0000000	261	537	A
AZIMUTH START*	R1110101111	243	516	A		+1+00000000	262	539	A
	11101011111	244	517	A		+1+00000000	263	540	C
	11101011111	245	519	C	AZIMUTH END*	1+000000000	264	541	A

KEY — 0 NO HIT
1 HIT
R POTENTIALLY DIFFERENT CELL (HIT)
+ GARBLED HIT

* COMPUTED FROM REPORT DATA ON MODE 2 TAPE

It is readily apparent from Table 8.29 that azimuth start declared by the CD for generation of the target report (computed from the target report data) occurs well past the point where the sliding window should have reached the leading edge threshold of six. This point occurred at either sweep 238 or 240 depending on what range cell the reply from sweep 228 went into. The trailing edge threshold computed from the report data agrees with the point where the sliding window falls to two hits; i.e., sweep 264.

In both of the previous anomalies illustrated, the different ranging techniques between the AI and CD were indicated as potential contributors to the occurrence of the observed anomalies. This anomaly can also be related to the ranging differences. It will be assumed that this is the case and it will be shown that the data is at least not inconsistent with the hypotnesis. The computed leading edge threshold from the target report data was sweep 243 as shown on Table 8.29. Assume that the oldest three replies (i.e., the hits to the far left of the window for sweep 243) were not included in this sliding window (i.e., they went into an adjacent window). The sliding window, under this assumption, first reaches the threshold of six hits on sweep 243. The validation threshold was reached on the prior Mode 3/A sweep, 241. It will be assumed that all the remaining replies went correctly into this sliding window. The validation of beacon code and altitude are not considered.

After the validation threshold is reached, two ungarbled replies with agreeing information pulses must be processed to validate each mode, respectively. The first Mode C reply after the validation threshold is reached occurs on sweep 242 and is ungarbled. Two more ungarbled Mode C replies occurred on sweeps 245 and 248, yet the altitude did not validate. Perhaps these were associated with a range cell other than the range cell of interest and were not used at all in the validation. There are four ungarbled Mode 3/A replies after sweep 241 and any two of these would cause validation of Mode 3/A with a code of 2732 which is what occurred.

Finally, the computed trailing edge threshold from the report data corresponds with the point where the sliding window reaches a level of two hits.

This example has presented an apparent failure of the CD to properly centroid a group of replies to produce a target report. It is theorized that the failure may have been caused by timing differences between the AI and CD which affect ranging. Some of the replies which are indicated by the AI as being identical in range may actually have been put in an adjacent range cell by the CD causing the centroiding computed in the CD to differ from the centroiding that would be predicted from Table 8.29.

8.5.7 Single Hits Being Used in Adjacent Range Cells

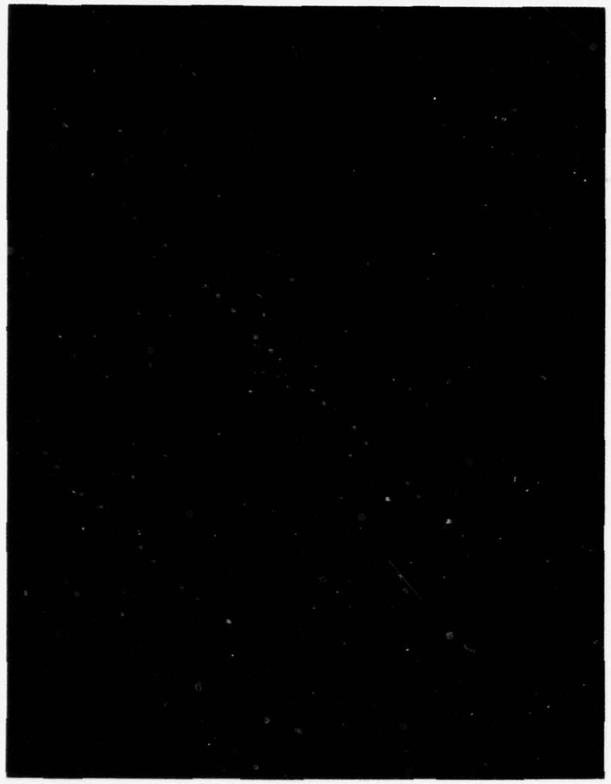
The example to be presented here is one of the more interesting anomalies that was documented. Figure 8.57 is a display of the reports and the associated replies. The data of interest are the two reports and group of replies running diagonally through the center of the display. The other report and replies at the lower left of the display are not being discussed. It is assumed that both of the reports of interest were generated from the group of replies in the center of the picture. The report data for these two reports is listed with Figure 8.57.

Report A occurs at 102.375 nmi with no validated beacon data. Report B occurs at 102.625 with validated beacon code and altitude. The range separation is 0.250 which definitely establishes the reports as being generated in adjacent range cells.

The replies are listed in Table 8.30. All the Mode 3/A replies are at 102.563 nmi with the exceptions of sweep 249, 250, and 252 which are at 102.594 nmi, 102.406 nmi, and 102.594 nmi, respectively. Noting that most of the replies are at 102.563 nmi, it is assumed that this group (at 102.563 nmi) generated at least one of the target reports. Since the separation between the reports was 0.250 nmi, the replies generating the two reports would have to be a minimum of 0.125 nmi apart. Only one reply, the one at 102.406 nmi on sweep 250, is separated by more than 0.125 nmi from 102.563 nmi. While range differences between the CD and the AI on the order of magnitude sufficient to throw replies into different range cells in the CD (which means a 1/32 nmi difference) may be reasonable, a difference on the order at least 0.125 nmi between CD ranging and AI ranging is quite a different story. In Section 4.2, an analysis of range jitter in the ACRBS including the CD was done and it was shown that large jitter can occur in the system. The AI interpreter is extracting replies at the BRG output so that the effect of all the jitters in the system including CD jitters up to this point would be reflected in the reply data. The additional jitter, which may exist but which was not accounted for in the range jitter analysis, would be introduced by the CD as a result of CD memory timing constraints. It is not actually known if such uncertainties are introduced by the CD, but some of the data presented thus far can be explained by the existence of such jitter. This jitter, if generated by CD memory, would not be expected to be nearly enough to introduce more than a 0.125 nmi uncertainty. Assuming that Report B at 102.625 nmi with validated beacon data is the correct report, an explanation for the erroneous report at 102.375 nmi has not been offered yet. An analysis of the sliding window contents is performed next.

FIGURE 8.57

ANOMALOUS REPLIES – SINGLE HITS USED IN ADJACENT RANGE CELLS



TAPE – MODE 2 12/16/75 #1
PHOTO – 1/28/76 #C

REPORT DATA –	A	B
REC	5	5
MSG	7	8
AZIMUTH	46.318	46.582
RANGE	102.375	102.625
RUN LENGTH	24	34
SRCH RINF	0	1
MODE 2		
VAL	0	0
CODE		
MODE 3A		
VAL	0	1
CODE		2773
MODE C		
VAL	0	1
ALTITUDE		21100

TABLE 8.30

REPLY DATA FOR 1/28/76 #C

REPLIES

REC	SWP	|---BEARING---| DEGREES	ACP|S	RANGE NAUT MI	MODE	CODE (ALT)	BRACKET DETECTION	SPI	GARBLE
4	234	44.473	506	102.563	3A	2773	100000000000000	0	0
4	235	44.561	507	102.563	3A	2331	100000000000000	0	1
4	236	44.648	508	102.563	C	21100	100000000000000	0	1
4	237	44.736	509	102.563	3A	2773	100000000000000	0	0
4	239	44.912	511	102.563	C	21100	100000000000000	0	0
4	240	45.088	513	102.563	3A	2773	100000000000000	0	0
4	241	45.176	514	102.563	3A	2773	100000000000000	0	0
4	242	45.264	515	102.594	C	21100	100000000000000	0	0
4	243	45.352	516	102.563	3A	2773	100000000000000	0	0
4	244	45.439	517	102.563	3A	2773	100000000000000	0	0
4	245	45.615	519	102.594	C	21100	100000000000000	0	0
4	246	45.703	520	102.563	3A	2773	100000000000000	0	0
4	247	45.791	521	102.563	3A	2773	100000000000000	0	0
4	248	45.879	522	102.594	C	21100	100000000000000	0	0
4	249	45.967	523	102.594	3A	2733	100000000000000	0	1
4	250	46.055	524	102.406	3A	7060	110000000000000	0	0
4	250	46.055	524	102.563	3A	2773	100000000000000	0	0
4	251	46.230	526	102.594	C	85400	110000000000000	0	1
4	251	46.230	526	102.813	C	109300*	100000000000000	0	1
4	252	46.318	527	102.594	3A	2732	100000000000000	0	1
4	253	46.406	528	102.563	3A	2773	100000000000000	0	0
4	254	46.494	529	102.594	C	21100	100000000000000	0	0
4	255	46.582	530	102.563	3A	2773	100000000000000	0	0
4	256	46.758	532	102.563	3A	2773	100000000000000	0	0
4	257	46.846	533	102.594	C	21100	100000000000000	0	0
4	258	46.934	534	102.563	3A	2673	100000000000000	0	0

Table 8.31 is the result of the sliding window analysis performed on the reply data of Table 8.30. The start and stop azimuth for both reports were computed from the report data and are pointed out in Table 8.31. The replies at different ranges on sweeps 249, 250, and 252 were included as hits for purposes of the analysis. Their inclusion or exclusion will not affect the leading edge declaration of either target report since leading edges occur before sweep 249, according to the target data.

Report B was found to have its azimuth start at sweep 243. Examination of sweep 243 in Table 8.30 shows that if all the replies coming in up to that point are in the same range cell, which was assumed when the sliding window data was developed, then six hits appear for the first time on sweep 243. This verifies the leading edge threshold data for Report B. Likewise, the trailing edge for Report B, computed to be at sweep 271, occurs when the sliding window first fall to two hits. Thus, ignoring Report A all together, the CD appears to have taken the replies of Table 8.30 and properly centroided them to produce Report B.

The generation of Report A remains a mystery. The leading edge was computed from Report A data to fall on sweep 244. However, the previous six replies were used to declare Report B which is in a different range cell from Report A. On sweep 244, one more reply is shifted into the sliding window. Even if this reply were incorrectly ranged by the CD, so that it went into another range cell, it is not sufficient to declare a leading edge for target Report A. Unless single replies are getting processed by the CD into two range cells on the same sweep, the generation of Report A is unexplainable.

One other possibility exists and in view of the impossibility of Report A, may be likely. This is that the AI erroneously wrote a report message on the Mode 2 tape. At any rate, problems such as this should be investigated to determine the source of the anomaly.

8.5.8 Azimuth Split

Azimuth splits were one of the five ambiguity types that were identified in the analysis of target reports discussed in Section 8.4. The characteristics are a group of two reports separated by less than a beamwidth in azimuth (order of 3°) and occurring at the same range. In the analysis of Section 8.4, the reports were also required to have the same discrete beacon code. This was done for ease in identifying the ambiguity and is not a fundamental property of azimuth splits. An example of a pair of target reports meeting the separation criteria was found in the reply data and documented. Figure 8.58 is a display of this example.

TABLE 8.31

SLIDING WINDOW HISTORY FOR 1/28/76 #C

	WINDOW	SWEEP	ACP	MODE		WINDOW	SWEEP	ACP	MODE
	00000000000	233				0111111+1+1	254	529	C
	00000000001	234	506	A		111111+1+11	255	530	A
	0000000001+	235	507	A		11111+1+111	256	532	A
	0000000001+	236	508	C		11111+1+111	257	533	C
	000000001+1	237	509	A		1111+1+1111	258	534	A
	00000001+10	238		A		111+1+11110	259	535	A
	00000001+10	239	511	C		111+1+11110	260	536	C
	0000001+101	240	513	A		11+1+111100	261	537	A
	000001+1011	241	514	A		1+1+1111000	262	539	A
(B) AZIMUTH START*	000001+1011	242	515	C		1+1+1111000	263	540	C
(B) AZIMUTH START*	00001+10111	243	516	A	(A) AZIMUTH END*	+1+11110000	264	541	A
(A) AZIMUTH START*	0001+101111	244	517	A	(A) AZIMUTH END*	1+111100000	265	542	A
(A) AZIMUTH START*	0001+101111	245	519	C		1+111100000	266	543	C
	001+1011111	246	520	A		+1111000000	267	545	A
	01+10111111	247	521	A		11110000000	268	546	A
	01+10111111	248	522	C		11110000000	269	547	C
	1+10111111+	249	523	A	(B) AZIMUTH END*	11100000000	270	548	A
	+10111111+1	250	524	A	(B) AZIMUTH END*	11000000000	271	549	A
	+10111111+1	251	526	C		11000000000	272	551	C
	10111111+1+	252	527	A		10000000000	273	552	A
	0111111+1+1	253	528	A		00000000000	274	553	A

KEY — 0 NO HIT
1 HIT
+ GARBLED HIT

* COMPUTED FOR REPORT DATA ON MODE 2 TAPE

It is evident that the pair of reports was generated by a fading of replies followed by a subsequent reappearance of replies. The target report data and reply data are both listed in Table 8.32. The range of each report is 42.875 nmi. The azimuth separation between them is 4.22°. One of the reports had a validated beacon code and altitude while the other had neither.

Because of the separation of the replies in azimuth, and the unusually long reply string, the event may be considered a sidelobe phenomena instead of an azimuth split. At such separations, it is difficult to distinguish the two types. This one was arbitrarily names an azimuth split because the TRAAP program used for target report analysis would classify it as such.

Examination of the code or altitude for each reply shows that the entire string was generated by the same aircraft (since they are the same code and same altitude for the whole length of the reply train). The break in the replies occurs from sweep 387 to 404 inclusive for a total of 18 missing replies, 12 Mode 3/A's and 6 Mode C's. Such a loss is sufficient to declare a trailing edge. Six Mode 3/A replies appear before the break which is insufficient to validate either Mode 3/A or Mode C data. After the break, sufficient data is present to detect and validate both Mode 3/A and Mode C. A sliding window analysis was not done for this example, because it was not necessary in order to see how the ambiguity was generated.

FIGURE 8.58

AZIMUTH SPLIT AND REPLIES

PHOTO — 2/10/76 #1

COLOR CODE —

AMBIGUOUS REPORTS — GREEN X

MODE 3/A REPLIES — RED

MODE C REPLIES — BLUE

RANGE RING INTERVAL — 5 NMI

AD-A038 492 JOHNS HOPKINS UNIV LAUREL MD APPLIED PHYSICS LAB F/G 17/7
SYSTEM DEFINITION AND INVESTIGATION OF ON-SITE PROCESSING OF EN--ETC(U)
SEP 76 J W THOMAS DOT-FA75WA-3553
UNCLASSIFIED APL/JHU-FP8-E-024-2 FAA-RD-77-12-2 NL

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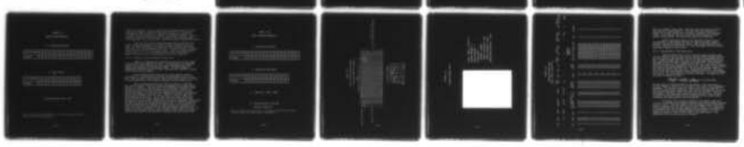

END
DATE
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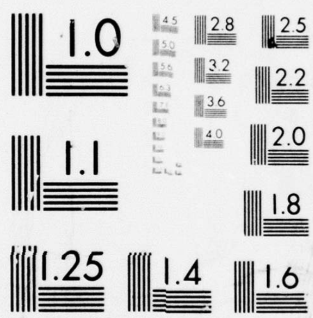

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 8.32

REPORT AND REPLY DATA FOR PHOTO 2/10/76 #1

REPORT DATA:

REC	MSG	TYPE	AZIMUTH	RANGE	RUN LNG	MOTE	FAA	AF	SRCH RINF	MODE 2 VAL	MODE 2 CODE	MODE 3A VAL	MODE 3A CODE	MODE C VAL	MODE C ALTITUDE
229	4	BCON	192.129	42.875	36	0	1	1	0	0		0		0	
229	6	BCON	196.348	42.875	104	0	1	1	1	0		1	3206	1	33000

REPLY DATA:

REC	SWP	MSG	BEARING DEGREES	BEARING ACP'S	RANGE NAUT MI	MODE	CODE (ALT)	BRACKET DETECTION	SPI	GARBLE
230	377	2	190.723	2170	42.906	3A	1206	100000000000000	0	0
230	378	2	190.898	2172	42.906	C	30500	100000000000000	0	0
230	380	1	191.074	2174	42.906	3A	3206	100000000000000	0	0
230	381	1	191.162	2175	42.906	C	33000	100000000000000	0	0
230	382	2	191.250	2176	42.906	3A	3206	100000000000000	0	0
230	383	2	191.426	2178	42.906	3A	3202	100000000000000	0	0
230	384	1	191.514	2179	42.906	C	33000	100000000000000	0	0
230	385	2	191.602	2180	42.906	3A	3206	100000000000000	0	0
230	386	2	191.689	2181	42.906	3A	3204	100000000000000	0	1
230	405	2	193.711	2204	42.844	C	-1000	100000000000000	0	0
230	405	3	193.711	2204	42.875	C	33000	100000000000000	0	1
230	406	2	193.799	2205	42.875	3A	3206	100000000000000	0	0
230	407	2	193.887	2206	42.875	3A	3206	100000000000000	0	0
230	408	4	193.975	2207	42.875	C	33000	100000000000000	0	0
230	409	3	194.063	2208	42.875	3A	3206	100000000000000	0	0
230	410	3	194.238	2210	42.875	3A	3206	100000000000000	0	0
230	412	2	194.414	2212	42.875	3A	3206	100000000000000	0	0
230	413	1	194.502	2213	42.875	3A	3206	100000000000000	0	0
230	414	1	194.590	2214	42.875	C	33000	100000000000000	0	0
230	415	1	194.766	2216	42.875	3A	3206	100000000000000	0	0

TABLE 8.31 (cont'd)

230	417	2	194.941	2218	42.844	C	33000	100000000000000	0	0
230	418	2	195.029	2219	42.875	3A	3206	100000000000000	0	0
230	419	2	195.117	2220	42.875	3A	3206	100000000000000	0	0
230	423	1	195.557	2225	42.875	C	33000	100000000000000	0	0
230	424	2	195.645	2226	42.844	3A	3206	100000000000000	0	0
230	425	2	195.732	2227	42.875	3A	3206	100000000000000	0	0
230	426	2	195.908	2229	42.875	C	33000	100000000000000	0	0
230	427	2	195.996	2230	42.875	3A	3206	100000000000000	0	0
230	428	1	196.084	2231	42.875	3A	3206	100000000000000	0	0
230	429	1	196.172	2232	42.844	C	33000	100000000000000	0	0
230	430	1	196.260	2233	42.875	3A	3206	100000000000000	0	0
230	431	1	196.436	2235	42.844	3A	3206	100000000000000	0	0
230	432	1	196.523	2236	42.875	C	33000	100000000000000	0	0
230	433	1	196.611	2237	42.875	3A	3206	100000000000000	0	0
230	434	1	196.699	2238	42.875	3A	3206	100000000000000	0	0
230	435	1	196.787	2239	42.875	C	33000	100000000000000	0	0
230	436	1	196.875	2240	42.844	3A	3206	100000000000000	0	0
230	437	1	197.051	2242	42.875	3A	3206	100000000000000	0	0
230	438	1	197.139	2243	42.875	C	33000	100000000000000	0	0
230	439	1	197.227	2244	42.875	3A	3206	100000000000000	0	0
230	440	1	197.314	2245	42.875	3A	3206	100000000000000	0	0
230	441	1	197.402	2246	42.875	C	33000	100000000000000	0	0
230	442	1	197.578	2248	42.875	3A	3204	100000000000000	0	1

8.5.9 Analysis of Range Jitter in Replies

In Section 8.4, the analysis of target reports, two of the problems considered were Range Splits and Mainbeam Reflections, both of which are target report ambiguities. It is suspected that the range splits are caused by jitter in the ranging of replies by the CD such that successive replies from a target will be randomly placed in one of two adjacent range cells. When a sufficient number of replies are placed in each of the adjacent cells (minimum of six each), a target report will be declared in both cells. The pair of targets generated will have an azimuth separation (usually) of less than 3° and a range separation that puts them in adjacent range cells (either 1/8 or 1/4 nmi).

Also in Section 8.4, it was suggested that mainbeam reflections*, which were observed exclusively in pairs with similar azimuth separation characteristics but larger range separations, were also caused by range jitter. In this case, replies are being placed in non adjacent range cells.

An analysis of the range jitter sources present in the system, from radar pretrigger to detection of the replies by the BRG in the CD was done. The results of this analysis are presented in Section 4.2. Based on this analysis, there is a reasonable probability that a range split will be generated from the range jitters present in the system. Furthermore, mainbeam reflections can be generated by this mechanism, but larger deviations, which occur with lower probabilities, are required. This lower probability is consistent with the observed rarity of mainbeam reflections.

The sources of range jitter in the system include the ATCBI and the transponder itself as well as the CD. The purpose of this section is to summarize those results of the jitter analysis in Section 4.2 that are applicable to the CD itself. Two sources of jitter in the CD were considered; the ARTG and the BRG. The ARTG was found to produce up to a 55.2 nsec jitter and the BRG was found to produce up to 103.6 nsec jitter, each with a uniform probability distribution (see analysis of Section 4.2 for clarification if necessary). The maximum difference between the ranges of any two successive replies from a transponder at fixed range that can be introduced by the CD is about 159 nsec or about .013 nmi. This variation is significant for targets which are close to a CD range cell boundary in actual range because the jitter then has the potential to cause successive replies to jump across the boundary into the adjacent cell. As indicated earlier in this section, there may be other sources of range uncertainty in the CD stemming from the memory processing constraints which affect the assigning of the replies to range cells.

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* Recall that the use of the word "reflection" may be a misnomer here.

While total system jitter is evaluated in Section 4.2, it is not related directly to the range split rates theoretically produced by the jitter models used. To perform such an analysis analytically involves a tedious mathematical procedure to develop the probability density function of the total system jitter which can then be used to predict range split rates. A simpler method is to perform a computer simulation. It is recommended that such a simulation be done, using the jitter model developed in Section 4.2, with additional modeling as necessary to evaluate the range split rates. Such an analysis would require only a small effort. The results could then be compared to observe range split rates whereupon the reasonableness of the range jitter theory would be established. If the predicted range split rate was substantially different from observed rates, the difference might be attributed to a malfunction in the CD processing, or a new theory might have to be developed. Such an analysis would be strongly aided by a concurrent analysis of replies from Mode 2 tapes, provided that the ranging problems (i.e., the apparent difference in AI range and CD range) can be resolved. Before the range split problem can be understood fully, it will be necessary to know if the CD is in fact placing replies from the same transponder randomly in adjacent cells. Several range splits and associated replies have been observed from Mode 2 data and all have the characteristics of the example given by Section 8.5.4, wherein the jitter was not evident from the AI data. Thus the proposed range jitter theory has not been directly verified, though much of the data collected is consistent with the range jitter theory.

8.6 ANALYSIS OF BEACON VIDEO

8.6.1 Introduction

The beacon video input to the CD is the third point in the processing chain where data is collected for analysis. The purpose of this step is to study the relationship between the beacon video and the resulting beacon replies which would indicate possible differences in the generation of replies from the beacon video.

First, several groups of replies of interest were selected for further analysis. Segments of the associated FR-950 tape of analog video were then defined as described in Section 8.2 such that the video which generated the replies of interest would be contained in them. The specification consisted of range and azimuth limits defining a "window" and a start time and end time for collecting the data. These parameters were used to operate the VQR machine which then quantized the designated regions and produced VQR tapes containing the beacon video information in quantized form for computer display and analysis.

The VQR machine is limited in that it can quantize only a certain amount of data per scan. The maximum size of the quantized region depends on the sampling rate. The range azimuth limits (dimensions of the window) may be varied to fill the memory buffer to capacity. A typical window size defined by the Laboratory in requests for VQR tapes was 8 nmi by 147 ACP's (~12°). The start and stop times for data collection were typically specified such that about twenty scans of data were quantized with the scan of interest falling approximately half way between the start time and stop time. The recording was made in this manner in order to avoid losing the scan of interest because of time inaccuracies that may exist.

Unfortunately, the range-azimuth window that was quantized in each case was displaced in azimuth from the desired region and did not contain the video corresponding to the selected replies. In several cases nothing but noise was quantized. This error, which will be discussed in more detail later, is thought to be a result of an azimuth offset somewhere in the process. Fortunately, a few of the windows quantized contained some actual transponder replies, though none were related to the originally selected group of beacon replies.

Some of the VQR windows containing transponder replies were documented using the VQR display analysis program. This section presents an illustration of VQR recorded transponder reply video and addresses how the information can be used. Beacon code and altitude are extracted from the video data and correlated with the associated reply data on AI Mode 2 reply tapes.

Because the windows actually obtained were not those requested, the occurrence of beacon replies within them was strictly a matter of chance. Thus the example presented herein is not associated with any of the previously identified anomalies. The purpose for presenting this data is to provide some insight into the usefulness of an analysis of VQR beacon video.

A brief explanation of the VQR data appears in Section 8.2.4. It may be to the reader's benefit to review this section before proceeding.

8.6.2 VQR Example

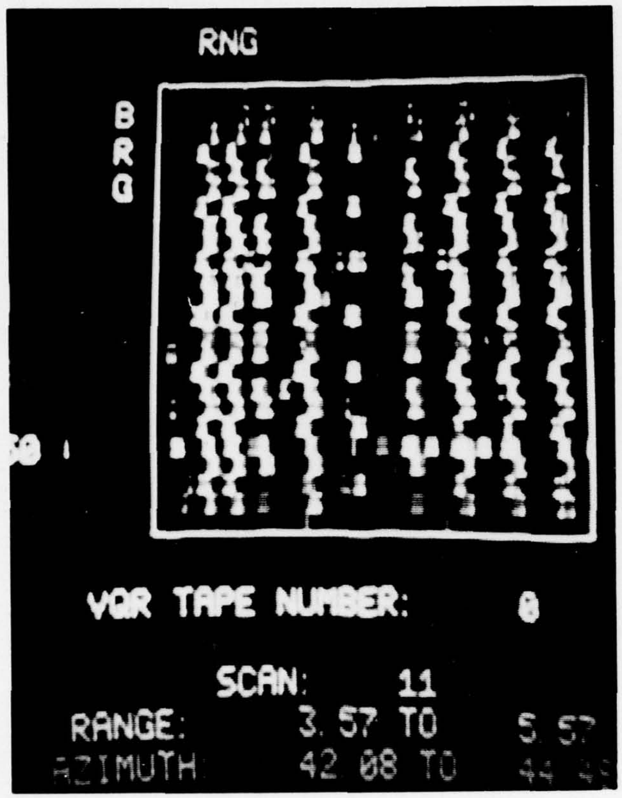
Figure 8.59 is a display of an expanded portion of window G, scan 11, made from VQR tape 2/24/76 #2. To obtain this display, window G, scan 11 from the tape was first displayed in its entirety (i.e., the entire 8 nmi x 147 ACP's was displayed). A ball tab controlled box was positioned around a smaller section of the display containing transponder reply video which was then expanded to produce the display of Figure 8.59 for a more detailed examination.

The figure depicts beacon video intensity as a function of range and azimuth. All of the data is displayed within the box defined by the white borders. The origin is located at the upper left corner of the box with the range increasing to the right along the horizontal axis and the azimuth increasing downward along the vertical axis. The video sampling rate used to generate the VQR tape from which this data was displayed was 96.57 nsec (this is 1/128 nmi for a two way transit of a signal in free space). The video received within the range bounds of the window was quantized once each sweep or about every 1.19 ACP's (.09°). Each video sample, therefore, is depicted by rectangular symbol on the display that is 1/128 nmi long (96.57 nsec) and 0.09° (1.19 ACP's) wide. The video intensity for each sample is revealed by the color of the symbol. Four thresholds are defined for this purpose and, as shown in the figure, the thresholds for this display were 10, 15, 20 and 50. Each number appears on the display in an associated color; i.e., blue, red, green, and white respectively. The video intensity of each sample is recorded on the VQR tape as a six bit binary word and the magnitude of this word is compared to the predefined threshold. The color in which each sample is displayed is that color associated with the highest threshold that the sample intensity equalled or exceeded. The absolute values of voltage or power are not available though it is known that the VQR input gain was adjusted to handle the dynamic range of the incoming video.

The range and azimuth of the origin, computed from references written on the VQR tape for each window quantized, are given below the display. The range of the origin is given as 3.57 nmi. The hardware range offset for this display, listed in Table 8.6 for window G is 96 nmi, putting the total range at the origin as determined from the VQR tape data at 49.57 nmi. There are 256 samples displayed along the range direction or a total of 2 nmi. The stop range is, therefore, 101.57 nmi at the right border of the display box. The stop range indicated on the display is 5.57 nmi, which, when added to the 96 nmi hardware offset, give 101.57 nmi. The azimuth axis spans 2.4° from 42.08° to 44.48°.

FIGURE 8.59

VQR DISPLAY



TAPE — VQR 2/24/76 #2

WINDOW — G

SCAN — 11

THRESHOLDS —

BLUE — 10

RED — 15

GREEN — 20

WHITE — 50

Each beacon reply, of course, occupies one sweep. The elapsed time from the F_1 leading edge to the F_2 leading edge is 20.3 μsec. At the 96.57 nsec sampling rate this is about 210 samples or an indicated 1.64 nmi on the display. Thus each reply will occupy a sweep in azimuth (about .09°) and extend about 1.64 nmi in range on the display. In the figure, an example of the sample dot size is shown next to each of the thresholds and appears as a small line next to each threshold number. The sample dot is oriented exactly as it is plotted so that its width is 1/128 nmi or 96.57 nsec and its length is 1.19 ACP's or 0.09°. The pulse width for each pulse in the beacon reply is normally 0.45 μsec and, as a result, each video pulse will normally consist of about five sample dots side by side (in range).

In Figure 8.59, the thresholds have been adjusted so that the pulses associated with each of the replies are visible. At the top left of the display, the F_1 pulse of the first reply is visible as the first cluster of five sample dots in white. The F_2 pulse at the upper right is also evident as are the six non zero information pulses between them. Looking down the display (increasing azimuth) it is evident that another pattern of information pulses is also present, this one with only five non zero pulses between the F_1F_2 pair. What is being shown by this is the transponder's replies to interrogations of different modes. The first pattern appears in two successive sweeps followed by the one reply of the second pattern, over and over. It can be deduced from this that the interlace is 3/A, 3/A, C which, of course, may be verified by looking in the data section (8.2.4).

Nearer the bottom of the display, a reply occurs which does not fit either of the two repeated patterns. This strange pattern has been created as a result of a reply from another transponder overlapping the reply of interest, probably causing a garble condition to occur. The spurious reply is called fruit, and came from a transponder being interrogated by a site other than Elwood. The first two replies at the top of the display are the same and are Mode 3/A replies, followed by a Mode C reply. Tracing this pattern through the successive sweeps, it is determined that the overlapped reply is a Mode 3/A reply. Numbering the replies in order from the top starting with one, the garbled reply is the nineteenth reply from the transponder of interest (the spurious reply which overlaps reply nineteen is not numbered).

8.6.2.1 Range Variations

Another interesting feature can be extracted from this display. The ranging is set up such that the actual range of the target producing the replies corresponds to the range of the leading edge of the F_2 pulse. The range of this pulse, and in fact the entire reply pulse group, varies from sweep to sweep. In particular, the Mode C replies appear to be closer in range by up to four sample widths or 1/32 nmi than adjacent Mode 3/A replies. In

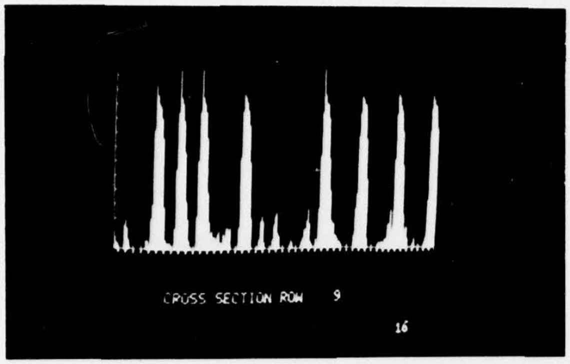
terms of time this is a difference of about 386 nsec. Because the offset is somewhat consistent for the Mode C replies, the cause of the phenomena is attributed to a transponder problem (maximum allowable difference between replies to different modes is 200 nsec at the transponder output). Variations in range between Mode 3/A replies are also present, though not as large. These variations are on the order of one to two samples or about 200 nsec.

While the variation between Mode 3/A replies and Mode C replies appears to be the result of a constant offset attributable to a transponder misadjustment, the variation between Mode 3/A replies appears to be the result of range jitter in the system. The actual variation in the range of the Mode 3/A replies at the video level before being processed by the CD is at least 100 nsec (i.e., a difference of 100 nsec could cause the observed jump of 2 sample dot widths. If such variations in the range of the replies inputted to the CD are commonplace, it would make little sense to attempt to detect the time of occurrence of these replies in the CD to within a few nanoseconds as has been proposed several times. It is recommended that the effects of the range jitter sources in the complete system be fully understood before attempts to reduce range jitter through CD modifications are undertaken. Understanding system jitters is not a particularly difficult problem. A theoretical analysis of system jitter appears in Section 4.2 and gives some insight into the problem. However, it is strongly recommended that total system range jitter at the input to the CD be physically measured and statistically described. Armed with this information, one could determine with confidence the effect of various proposed modifications to the CD to reduce range jitter problems.

8.6.2.2 Single Sweep Analysis

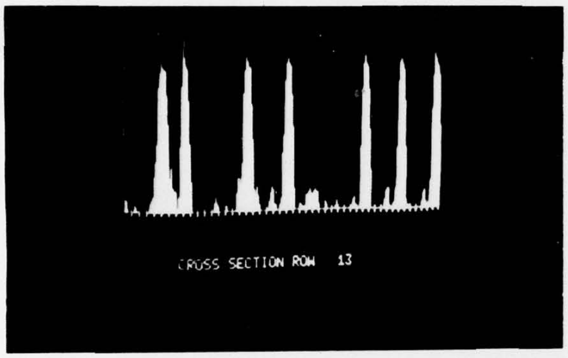
Another feature of the VQR display program is the ability to select a sweep and plot the video amplitude on a rectangular coordinate axis as a function of range. One Mode 3/A sweep and one Mode C sweep were selected from Figure 8.59 and plotted in this way to produce Figure 8.60a and b. On the plots, the vertical axis is amplitude and the horizontal axis is range. Each tic interval on the horizontal axis represents five sample widths of 482.85 nsec (0.038 nmi). Each tic interval on the vertical axis is five units video amplitude. Figure 8.60c illustrates the pulse positions to the scale of Figures 8.60a and b.

Consider first the Mode 3/A reply, Figure 8.60a. The "U. S. National Standard for the IFF Mark X(SIF)/Air Traffic Control Radar Beacon System Characteristics" specifies the nominal pulse slope and allowable tolerances for each pulse in the transponder reply pulse train. This information is illustrated by Figure 8.61. As the figure shows, the pulse duration or pulse width, pulse rise time and pulse decay time are defined in terms of peak amplitude A. The pulse width of the individual pulses shown by Figure 8.60a may be compared to this standard. Pulse widths, measured from Figure 8.60a, are at least seven sample intervals (0.68 μsec), even allowing for the



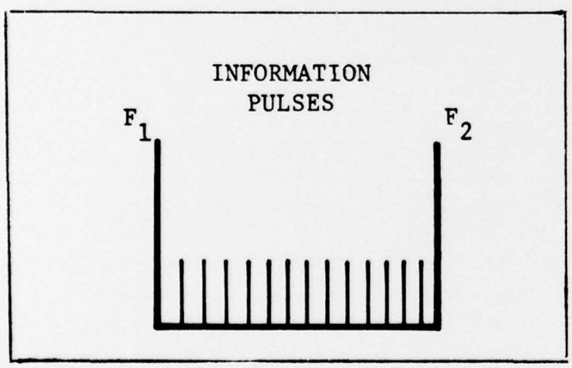
A) MODE 3/A REPLY

BEACON CODE: 3710



B) MODE C REPLY

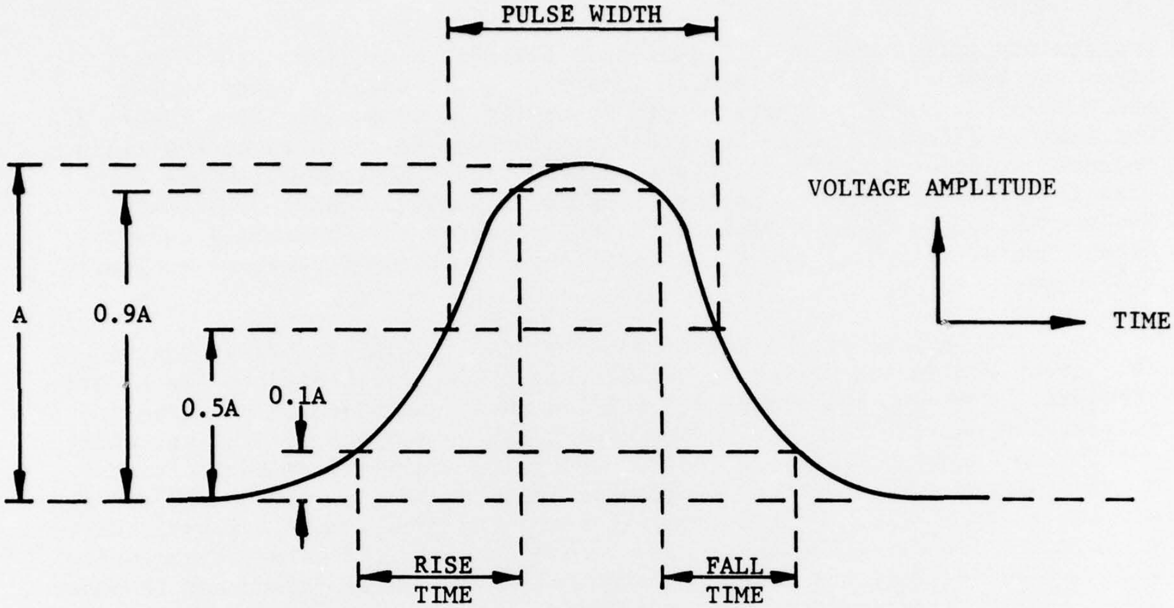
ENCODED PRESSURE
ALTITUDE: 8200 FEET



C) PULSE POSITIONS TO SCALE OF PHOTOGRAPHS

FIGURE 8.60
VIDEO AMPLITUDE VS RANGE (TIME)

TAPE	VQR 2/24/76 #2
WINDOW	G
SCAN	11
VERTICAL AXIS	AMPLITUDE — 5 PER TIC
HORIZONTAL AXIS	RANGE (TIME) — 5 SAMPLES/TIC
	EA. SAMPLE 1/128 NMI (96.57 NSEC)



Pulse Amplitude (A): The peak voltage amplitude of the pulse.

Pulse Duration: The time interval between 0.5A on leading and trailing edge of the pulse.
[Nominal 0.45 ± 0.10 μsec]

Pulse Rise Time: The time interval between 0.1A and 0.9A on the leading edge of the pulse.
[Between 0.05 and 0.10 μsec]

Pulse Decay Time: The time interval between 0.9A and 0.1A on the trailing edge of the pulse.
[Between 0.05 and 0.20 μsec]

FIGURE 8.61

TRANSPONDER REPLY PULSE SHAPE SPECIFICATIONS
AFTER DOT/FAA ORDER 1010.51A (8 Mar 1971)*

*Reference 21

uncertainty introduced by the sampling. Likewise rise times and decay times are both at least two sample intervals (0.19 μsec). Decay times are more often at least three sample intervals (0.29 μsec). From Figure 8.61 the maximum allowable pulse duration is 0.55 μsec as compared to the minimum measured duration from Figure 8.60a of 0.68 μsec. Maximum allowable rise time is 0.10 μsec compared to the measured value of at least 0.19 μsec. Maximum allowable decay time is 0.20 μsec compared to the minimum measured decay time of 0.19 μsec and the more frequently measured value of at least 0.29 μsec.

The net result of all of this is that the pulses being observed are spread out in time relative to the pulse shapes specified by the ATCRBS standard. However, the standard specifies the pulse shape at the transponder output, and not the received pulses, which may be subject to time spreading due to the frequency response loss of receiving equipment or in the transmission medium. The observed time spreading of pulses is not considered a problem at this time. Nonetheless, it is recommended that, if future analyses of beacon video using VQR tapes are planned, wherein the pulse characteristics may be studied, the source(s) of the time spreading (frequency response loss) should be determined. The recommendation is made primarily because the FR-950 recorder and VQR machines are both potential sources of this loss. Since neither of these pieces of equipment are in operational systems, modifications made to the CD based on observed pulse characteristics which reflect losses introduced by them would be of doubtful value.

8.6.2.3 Beacon Code

Next, the pulse spacing and beacon code may be extracted from Figure 8.60a. The spacing between the pulses prescribed by the ATCRBS standard is 1.45 μsec. A plot was made to the scale of photographs shown in Figure 8.60 with lines spaced at 1.45 μsec intervals to indicate pulse positions. This plot or grid is shown in Figure 8.60c. The grid was lined up with the reply pulse train of Figure 8.60a for comparison. It was first verified that the pulse interval is 1.45 μsec. Some minor deviations were measurable but these are caused by distortions introduced by the CRT. Next, the information pulses were extracted. This is shown in Table 8.33a, b, and c. Under 8.33a, "Extracted Pulse Data", the pulse positions are listed in the order in which they appear in Figure 8.60a. The information is rearranged as prescribed by the ATCRBS standard to form the beacon code word in Table 8.33b and finally the octal equivalent, the beacon code, is given in 8.33c and is 3710.

8.6.2.4 Mode C Reply

Consider the Mode C reply of Figure 8.60b. The pulse shapes and pulse spacing are about the same as those for Figure 8.60a so extraction of the encoded altitude is the primary task here. The steps are listed in

TABLE 8.33

MODE 3/A CODE EXTRACTION

a. Extracted Pulse Data*

Pulse Position	F_1	C_1	A_1	C_2	A_2	C_4	A_4	X	B_1	D_1	B_2	D_2	B_4	D_4	F_2
Contents	1	1	1	0	1	0	0	0	1	0	1	0	1	0	1

b. Mode 3/A Code

Pulse Position	A_4	A_2	A_1	B_4	B_2	B_1	C_4	C_2	C_1	D_4	D_2	D_1
Contents	0	1	1	1	1	1	0	0	1	0	0	0

c. Extracted Beacon Code: 3710

*The X bit is not used in ATCRBS. If it were nonzero, the reply of Figure 8.60a would be questionable.

Table 8.34 a through d. The bit values are first listed exactly in the order in which they appear in Figure 8.60b as shown by Table 8.34. The bits are rearranged as shown in Table 8.34. The bits D_2 through B_4 in Table 8.34 are a grey code representing the altitude to an accuracy of 500 feet. Bits C_1 through C_4 represent a correction term to be added to the altitude encoded in the grey code. Bit D_1 is not used. Table 8.35 is used to decode the altitude.

First the grey code is decoded using Table 8.35a, which gives the number of 500 foot increments from -1000 feet being represented by the grey code. The number determined for the sample at hand is eighteen which gives 8000 feet. The C bits are decoded using 8.35b. The grey code bits, D_2 through B_4 are added for a total of four which is even. In the even column of 8.33b next to C_1, C_2, C_4 = 1, 0, 0, the number "two" is read. Thus 200 feet is added to 8000 feet to get the result shown in Table 8.34d, 8200 feet.

8.6.2.5 Comparison with Corresponding AI Mode 2 Data

Window G, as requested by the Laboratory, was to have a start range of 99 nmi and a start azimuth of 447 ACP's. As noted however, the specified windows did not contain the desired video signals indicating that the VQR windows were displaced from the desired location. The first problem in comparing the VQR video data with AI Mode 2 reply data was, therefore, location of the correct group of replies.

Since the specified VQR start and stop times contained the scan of interest for a selected group of replies, the approximate location on the Mode 2 tape was known. Several scans of report data around the scan of interest for the selected replies were therefore displayed from the AI Mode 2 tape.

Next, the extracted beacon code, 3710, and altitude of 8200 feet were used to pinpoint the group of replies corresponding to the video actually quantized in window G. This was done by first searching the displayed report data for a beacon report with the proper code and altitude. Finally, the associated AI Mode 2 tape reply data was displayed and compared to the VQR data for confirmation. Figure 8.62 is the display of the report and associated replies that correspond to the VQR video. Table 8.36 lists the report and reply displayed in the figure. As the table shows, the report, which is at 101.875 nmi and 32.871°, has a beacon code of 3710 and an altitude of 8200. The reply data can be directly compared with the video, as displayed in Figure 8.59. The number of replies is the same and the modes listed in Table 8.36 agree with the mode interlace pattern determined for Figure 8.59. It was pointed out in Figure 8.59 that one of the replies was either overlapped or interleaved with a reply from another transponder so that a potential garble situation exists. As Figure 8.62 shows, there were two replies decoded for this sweep, one at about the same range (almost at the position of the green report dot) and the other

TABLE 8.34

MODE C ALTITUDE EXTRACTION

a. Extracted Pulse Data*

Pulse Position	F_1	C_1	A_1	C_2	A_2	C_4	A_4	X	B_1	D_1	B_2	D_2	B_4	D_4	F_2
Contents	1	1	0	0	1	0	1	0	0	0	1	0	1	0	1

b. Hybrid Grey Code Format

Pulse Position	D_1	D_2	D_4	A_1	A_2	A_4	B_1	B_2	B_4	C_1	C_2	C_4
Contents	0	0	0	0	1	1	0	1	1	1	0	0

c. (500 x 18) - 1000 = 8000

d. Correction Factor = 200 feet

Altitude = 8200 feet

*The X bit and D_1 bit are not used. If either of these had been nonzero in Figure 8.60b, the reply would be questionable.

TABLE 8.35

MODE C ALTITUDE DECODING TABLES

a. Grey Code (500 Foot Increments)

TABLE

UNIT DISTANCE REFLECTED BINARY CODE FOR 8 BITS

A_4, B_1, B_2, B_4, Pulses (columns); C_2, D_4, A_1, A_2 Pulses (rows)

	0000	0001	0011	0010	0110	0111	0101	0100	1100	1101	1111	1110	1010	1011	1001	1000
0000	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0001	31	30	29	28	27	26	25	24	23	22	21	20	19	$\boxed{18}$	17	16
0011	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
0010	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
0110	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
0111	95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	80
0101	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111
0100	127	126	125	124	123	122	121	120	119	118	117	116	115	114	113	112
1100	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
1101	159	158	157	156	155	154	153	152	151	150	149	148	147	146	145	144
1111	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175
1110	191	190	189	188	187	186	185	184	183	182	181	180	179	178	177	176
1010	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207
1011	223	222	221	220	219	218	217	216	215	214	213	212	[illegible]	[illegible]	[illegible]	208
1001	224	225	226	727	228	229	230	231	232	233	234	235	236	237	238	239
1000	255	254	253	252	251	250	249	248	247	246	245	244	243	242	241	240

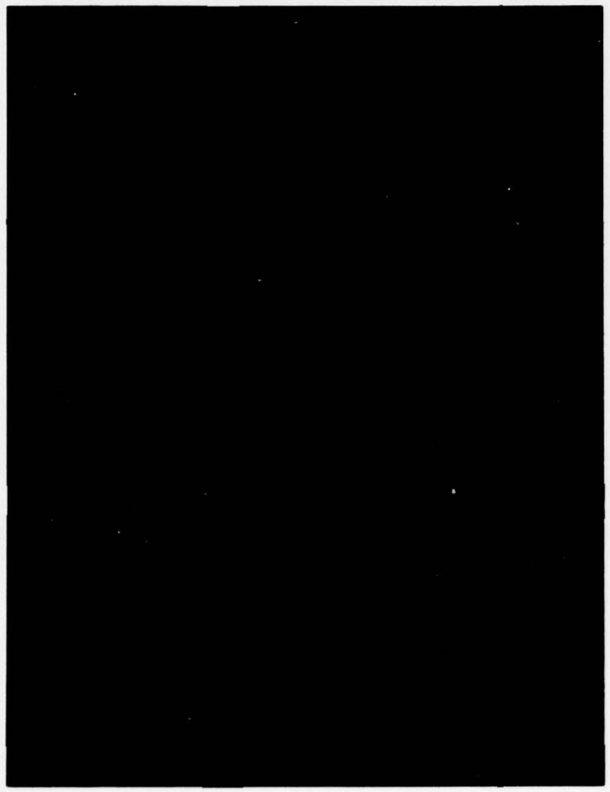
255 increments (500 foot each)
Giving altitude from -1000 feet to 127,000 feet

b. 100 Foot Increments

100 FOOT INCREMENT TABLE				
100 FOOT PULSES			SUM OF DIGITS OF GRAY CODE	
C_1	C_2	C_4	ODD	EVEN
0	0	1	7	8
0	1	1	6	9
0	1	0	5	0
1	1	0	4	1
1	0	0	3	$\boxed{2}$

FIGURE 8.62

AI MODE 2 REPLY DATA



TAPE — MODE 2 12/16/75 #1

REPORT RECORD — 3

REPLY RECORD — 4

COLOR CODE —

REPORT — GREEN

MODE 3/A REPLIES — RED

MODE C REPLIES — BLUE

RANGE RING INTERVAL — 2 NMI

TABLE 8.36

REPORT AND REPLY DATA

Tape: Mode 2 12/16/75 #1

REC	MSG	TYPE	AZIMUTH	RANGE	RUN LNG	MOTE	FAA	AF	SRCH RINF	MODE 2 VAL	MODE 2 CODE	MODE 3A VAL	MODE 3A CODE	MODE C VAL	MODE C ALTITUDE
3	15	BCON	32.871	101.875	34	0	1	1	1	0		1	3710	1	8200

WINDOW G
SCAN 11

REC	SWP	MSG	BEARING DEGREES	BEARING ACP'S	RANGE NAUT MI	MODE	CODE (ALT)	BRACKET DETECTION	SPI	GARBLE
4	105	2	31.025	353	101.844	3A	3710	100000000000000	0	0
4	106	2	31.113	354	101.844	3A	3710	100000000000000	0	0
4	107	2	31.201	355	101.813	C	8200	100000000000000	0	0
4	108	2	31.289	356	101.844	3A	3710	100000000000000	0	0
4	109	1	31.377	357	101.844	3A	3710	100000000000000	0	0
4	110	1	31.553	359	101.813	C	8200	100000000000000	0	0
4	111	1	31.641	360	101.844	3A	3710	100000000000000	0	0
4	112	1	31.729	361	101.844	3A	3710	100000000000000	0	0
4	113	1	31.816	362	101.813	C	8200	100000000000000	0	0
4	114	1	31.904	363	101.844	3A	3710	100000000000000	0	0
4	115	1	31.992	364	101.844	3A	3710	100000000000000	0	0
4	116	1	32.168	366	101.813	C	8200	100000000000000	0	0
4	117	1	32.256	367	101.844	3A	3710	100000000000000	0	0
4	118	2	32.344	368	101.844	3A	3710	100000000000000	0	0
4	119	2	32.432	369	101.813	C	8200	100000000000000	0	0
4	120	3	32.520	370	101.844	3A	3710	100000000000000	0	0
4	121	3	32.695	372	101.844	3A	3710	100000000000000	0	0
4	122	3	32.783	373	101.813	C	8200	100000000000000	0	0
4	123	2	32.871	374	101.594	3A	2637	101000000000000	0	0
4	123	3	32.871	374	101.844	3A	3000	100000000000000	0	1
4	124	1	32.959	375	101.844	3A	3710	100000000000000	0	0
4	125	2	33.047	376	101.813	C	8200	100000000000000	0	0
4	126	2	33.135	377	101.875	3A	3710	100000000000000	0	0

reply at a slightly closer range. Table 8.36 shows that these two replies were received on sweep number 123. The reply from the transponder of interest is at range 101.844 and is indicated as garbled in the garble bit column. Notice that the Mode 3/A code was incorrectly reported as 3000 because of the garbling. The interfering reply is at 101.594 nmi.

Another identifying feature of the VQR video in Figure 8.59 is the difference in range between the Mode 3/A replies and Mode C replies. The Mode C replies are consistently closer. This is also observable in the AI Mode 2 reply data of Table 8.36; i.e., Mode 3/A replies are at 101.844 nmi while Mode C replies are at 101.813.

8.6.2.6 Determination of VQR Window Offset

Since the VQR data and AI Mode 2 reply data agree in beacon code, altitude, number of replies, mode interlace pattern, range difference pattern, and on the garbled reply position, the two are clearly corresponding sets of data. Having concluded this, the offset of the VQR window can be ascertained. The range of the first reply is measured from Figure 8.59. This is done by measuring the range of the F_2 bracket pulse of the first reply from the origin of the plot which yields approximately 101.45 nmi. The AI Mode 2 data indicates this reply at 101.844 from Table 8.36. The VQR window indicates ranges at about 0.4 nmi less than the reply data, a negligible difference. The azimuth of the first reply is determined by first observing that it is the second sweep from the top. The first sweep is at 42.08° or 479 ACP's. The number of ACP's per sweep is computed as follows:

$$\frac{4096 \text{ ACP's}}{\text{Scan}} \times \frac{1 \text{ Scan}}{9.6 \text{ Sec}} \times \frac{\text{Sec}}{360 \text{ Sweeps}} = 1.19 \text{ ACP/s Sweep}$$

Thus the reply is at about 480 ACP's on the VQR data. This same reply is 127 ACP's behind or 353 ACP's in the AI Mode 2 data, which is not a negligible difference. The VQR start azimuth for window G was to have corresponded to 447 ACP's in the AI Mode 2 reply data. With the 127 ACP difference, the actual start azimuth obtained in terms of AI Mode 2 data was 320 ACP's. Since the centroiding of the replies was verified using the AI Mode 2 data, and shown to correctly produce the azimuth which is outputted by the CD under normal conditions, the problem must be in the VQR process.

The problem could possibly be related to the azimuth preset used in the CD. Once each scan, an azimuth reference pulse from the antenna pedestal is sent to the CD. When this signal occurs, the azimuth counter in the CD at Elwood is supposed to be 127 ACP's prior to zero or (4096 - 127) = 3969 ACP's. It is possible that when the VQR parameters were established, the azimuth was counted from 0 ACP's at the azimuth reference pulse instead of -127 ACP's causing the window to start 127 ACP's prior to the desired point. This explanation has not yet been proved or disproved.